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Above Ground Gamma Ray Logging for Locating Structures and Areas Containing Elevated Levels of Uranium Decay Chain Radionuclides

Office of Radiation Programs, Las Vegas, Nev.

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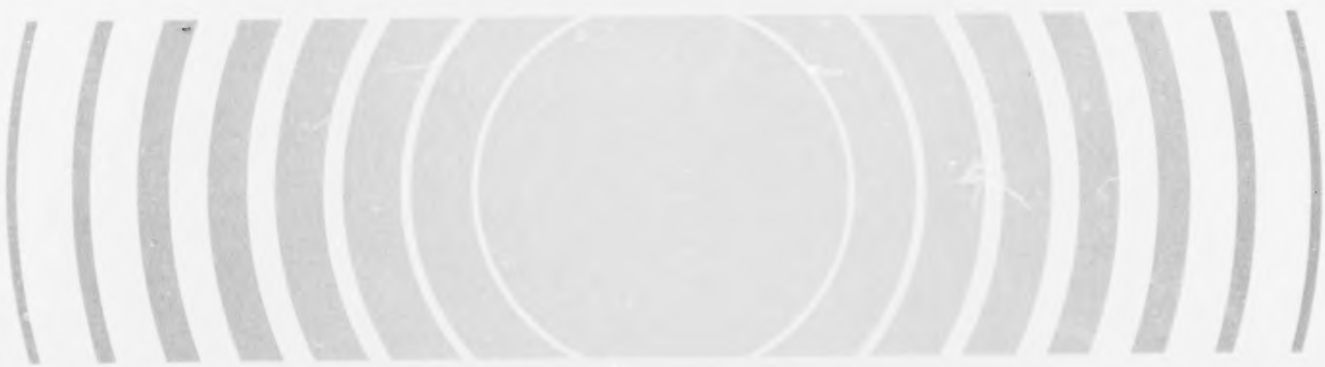

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This report describes the construction and operation of a mobile gamma ray logging system used to locate areas and structures containing elevated levels of natural uranium decay chain radionuclides. The detector system consists of a sodium iodide crystal coupled to four photomultiplier tubes and associated electronic system which permits both an audible indication and a strip chart recording of gamma ray photon count rates. The crystal is surrounded by lead shielding, to reduce incident background radiation, with a collimator port to define the area of observation. Under normal operations, the detector assembly is mounted in a van at about two meters above the ground surface and gamma ray logs are obtained while travelling at about 16 kilometers per hour (10 mph). This system has been used extensively in the Pocatello and Soda Springs, Idaho areas and identified about 1900 locations where phosphate slag has been used for various construction purposes. The system has also been used in several other communities to identify locations where uranium mill tailings or pumice, containing slightly elevated concentrations of natural radioactivity, was used for construction purposes. Although this mobile system has proven very successful as a rapid screening method for identifying areas or structures with slightly elevated radiation levels, only a more specific radiation survey can determine the exact exposure rate and specific construction usage of the building materials containing natural radioactive materials.

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ABOVE GROUND GAMMA RAY LOGGING FOR LOCATING STRUCTURES AND AREAS CONTAINING ELEVATED LEVELS OF URANIUM DECAY CHAIN RADIONUCLIDES

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April 1978

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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation, and to promote development of controls necessary to protect the public health and safety. This report describes a mobile gamma ray logging system which was used to rapidly screen areas and structures for elevated levels of uranium decay chain radionuclides, and presents the results of surveys conducted in selected areas of the western United States. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

Donald W. Hendricks
Director, Office of
Radiation Programs, LVF

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INTRODUCTION

Naturally occurring uranium is present throughout the earth's crust. The most abundant uranium isotope, uranium-238, is radioactive and is the parent of a long chain of radioactive daughters. Because of the relatively long half-life of uranium-238, all of the daughters are in radioactive equilibrium; however, they may not be at the same location because chemical and physical processes may have separated them from their respective parents.

The normal concentration of uranium in the earth's crust is approximately four grams per ton (about 0.00044 percent). Various ores (e.g., uranium, phosphate, gold and copper ores) contain increased uranium concentrations up to several thousand times the normal content. Ore mining and processing enhances the contact and distribution of uranium decay chain radionuclides in the biosphere.

Increased concentrations of naturally occurring radionuclides are also found in coal, lignites and oil shales. Their combustion will further increase the concentration of uranium decay chain radionuclides in the biosphere.

Several products and wastes, containing elevated levels of radioactivity, from the various ore mining and processing industries are being used for commercial purposes. Specifically, uranium mill tailings and phosphate slag have been used for construction and road paving but their use has been sporadic and widely scattered throughout entire communities and areas. In order to evaluate the radiological impact from this use, it is necessary to locate and identify these locations. One approach, used in the past, was to mount a scintillation detector in a vehicle and traverse or "scan" areas in order to locate anomalous count rates. The use of phosphate slag in road paving has raised some problems in identifying structures containing slag because of radiation interference from the road materials. A mobile gamma ray detector was designed and built to locate structures and areas which have elevated

radiation levels while in the presence of other interfering gamma radiation fields. This report describes the complete scanner detection system. Gamma ray logs, produced by the system at a variety of locations, are discussed in detail. Additional applications and uses of the "mobile logger" are also discussed.

SUMMARY AND CONCLUSIONS

This report describes the construction and operation of a mobile gamma ray logging system used to locate areas and structures containing elevated levels of natural uranium decay chain radionuclides. The detector system consists of a sodium iodide crystal coupled to four photomultiplier tubes and associated electronic system which permits both an audible indication and a strip chart recording of gamma ray photon count rates. The crystal is surrounded by lead shielding, to reduce incident background radiation, with a collimator port to define the area of observation. Under normal operations, the detector assembly is mounted in a van at about two meters above the ground surface and gamma ray logs are obtained while travelling at about 16 kilometers per hour (10 mph). This system has been used extensively in the Pocatello and Soda Springs, Idaho areas and identified about 1900 locations where phosphate slag has been used for various construction purposes. The system has also been used in several other communities to identify locations where uranium mill tailings or pumice, containing slightly elevated concentrations of natural radioactivity, was used for construction purposes. Although this mobile system has proven very successful as a rapid screening method for identifying areas or structures with slightly elevated radiation levels, only a more specific radiation survey can determine the exact exposure rate and specific construction usage of the building materials containing natural radioactive materials.

DETECTOR ASSEMBLY

I. Design Criteria

When used by the construction industry, uranium mill tailings and phosphate slag have been primarily used as bedding materials for concrete foundations and/or driveway slabs. Some slag has also been used as aggregate in concrete. Gamma radiation emitted by the bedding material and/or slab along the same plane as the slab is subject to self-absorption and to attenuation by the building footing and adjacent earth, while gamma radiation emitted above the slab plane is subject to some self-absorption and attenuation from the slab as well as the structure (Figure 1). The gamma photon flux should be higher above the slab plane; therefore, the best position for the detector should be such that it can "look" down on the structure's slab. Ideally, it is advantageous to mount the detector as high as possible in the transport vehicle in order that the slabs may be "viewed" from above. Increasing the operational height of the detector has two additional benefits. It is possible to "look" over parked cars, and it reduces somewhat the elevated ambient radiation levels which originate from streets paved with slag.

II. Carrier Van

The carrier vehicle chosen to transport the detector assembly was a 3/4 ton Chevrolet van with a camper shell roof. This roof extends the van's height by 66 cm and permits the operation of the detector at an elevation of about 2 meters above the road surface. Two electrical charging circuits are used in the van. One circuit is for the electrical systems of the van and an electrical winch which is used to raise and lower the shielded crystal assembly. The other charging circuit is used for the operation of the detector's electronic equipment. Each charging circuit has its own alternator. The vehicle operator has a remote panel to view the status of the D.C. voltage, A.C. voltage, and count rate being recorded on a strip chart. For normal transportation, the crystal assembly remains lowered on the floor of the van but during "scanning" operations, the crystal assembly is elevated as described below.

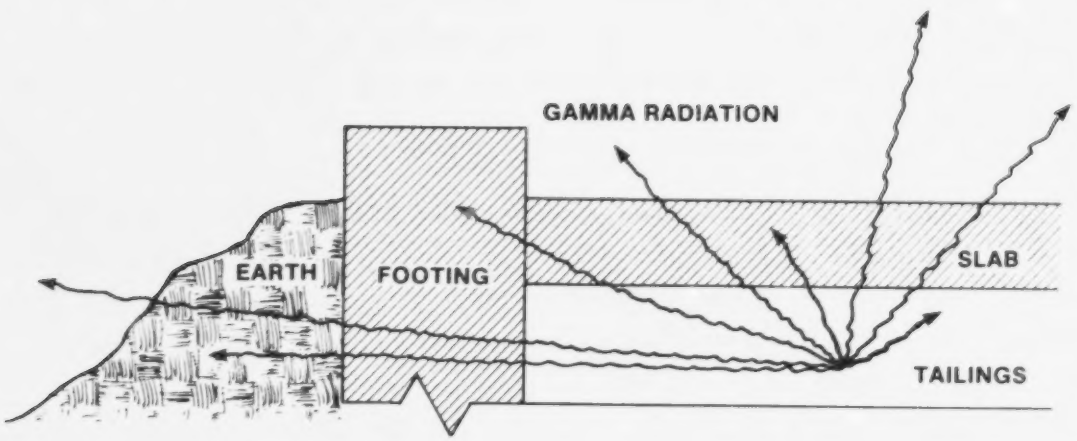


Figure 1. Relative shielding effects from building construction with tailings or slag used as bedding material.

III. Detector Electronics

The radiation detector used with the system is a sodium iodide (thallium activated) crystal having the shape of a solid right cylinder with a diameter of 23 cm and height of 10 cm. The crystal is hermetically sealed in an aluminum can with a wall thickness of 0.048 cm. Light signals, produced by the interaction of gamma ray photons within the crystal, impinge on four (7.6-cm diameter) photomultiplier tubes optically coupled to the crystal. The output signals from the photomultiplier tubes are fed into a battery operated preamplifier.

High voltage from a Canberra Model 3002 high voltage power supply is fed in parallel to each photomultiplier tube and the signal from each tube is summed at the input to the preamplifier. The preamplifier is a modified Technical Measurements Corporation unit. The preamplifier modifications were made to improve pulse input shaping and internal battery operation. The preamplifier is used only for signal shaping and for impedance matching to drive low impedance signal lines (50 ohms). The electronic system consists of a Nuclear Data Model ND512 Amplifier and Single Channel Analyzer, Nuclear Data Model ND776 Linear Ratemeter, and a Hewlett Packard Model 7155 Strip Chart Recorder.

The ND512 amplifier gain stability is very good and the unit offers a wide variety of input-output functions needed for experimental operations. The ND776 Linear Ratemeter measures count rates from 1 to 100,000 counts per second (cps), selected on nine linear ranges. Decoder outputs are provided at 0-1 mV; 0-10 mV; or 0-100 mV full scale. Other features include a 1 to 100 percent scale, suppression for background subtraction, and a standard error of 1, 3, or 10 percent referenced to full scale. An audible tone frequency varies with the count rate. The strip chart recorder is operated from the vehicle's 12-volt system and has a variety of input signal configurations and various chart speeds.

IV. Hoisting Cart Design

The basic concern in the design of the cart assembly was the size and weight of the shielded sodium iodide crystal. The crystal and lead shield assembly measured 41 cm in diameter with a weight of approximately 450 kilograms. With these two features in mind, the cart was designed with a 2-cm thick aluminum base plate and eight guide wheels. With this amount of weight being supported, additional strength was provided by a 10-cm x 7.6-cm I-beam support which was centered below the middle of the cart. All weight was supported by this beam establishing a two-reaction one-load type system.

A guide system was developed to prevent any horizontal movement of the crystal as a result of slippage while the cart was being raised or lowered. Eight guide wheels were mounted to provide minimum deflection of the cart when installed between the four I-beam cart supports. The wheels were mounted on a 3-cm diameter shaft with two bearings per wheel. The size of shaft and bearing design was established by materials on hand and by the fact that standard bearing sizes were readily available. Because the wheels are approximately 9-cm in width, two end thrust bearings were used to provide uniform loading on each wheel.

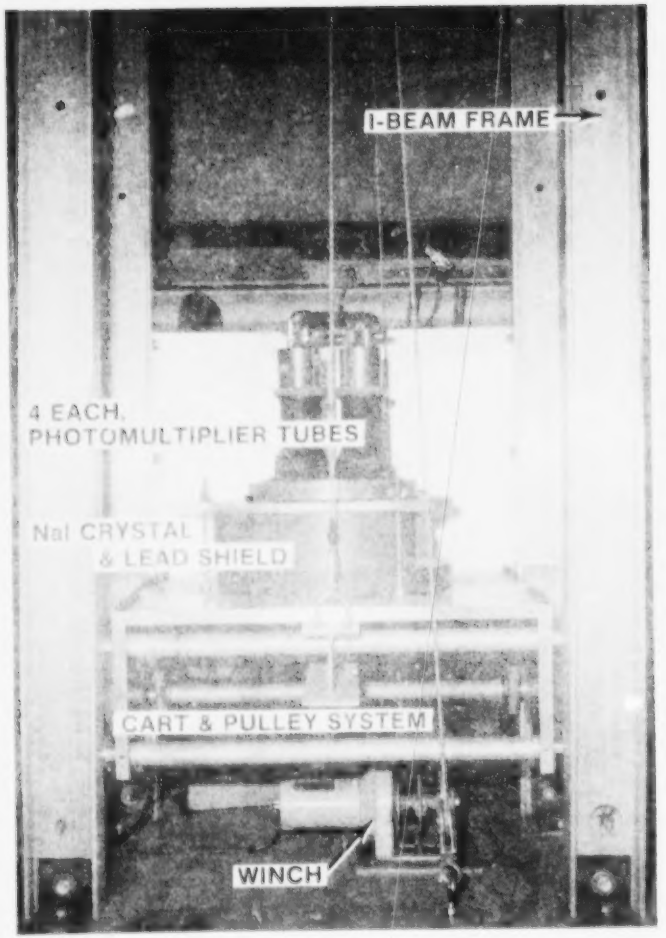
V. Hoist Design

In order to achieve maximum crystal height during operation, a lift or hoist system was constructed. To accomplish both stability and strength, four equal length I-beams were used vertically. These I-beams measure 10-cm x 7.6-cm x 183-cm and were made from 6061-T6 aluminum. The inside portion of the I-beams are used as guides for the eight wheels of the hoisting cart. The I-beams are mounted securely to the van floor and with diagonal supports to the side panels. With the rails mounted, it was possible to construct a hoisting system using an ATV 1500 "Superwinch" and a simple pulley system. With the winch located on the floor, centered beneath the cart, two cables are run from the winch through a set of bottom pulleys to the top support where the cables are guided through two more pulleys. From there, the cables were attached to the cart assembly. As the winch motor is activated, the pulley system raises or lowers the crystal to the desired operational position. Figure 2 shows several views of the actual detector assembly mounted in the van.

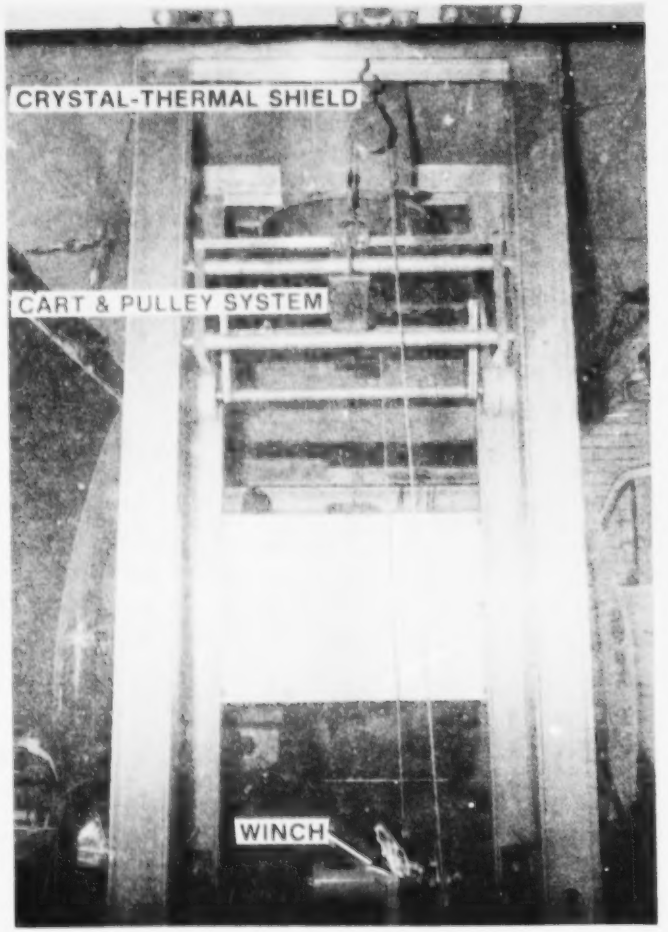
Mobile Gamma Ray Logging System - Transport Vehicle

Strip Chart Recorder and Operator

Figure 2. Photographs of van and detector assembly.



Crystal in Lowered Position
(Thermal Shield Removed)



Crystal in Raised Position
(Thermal Shield in Place)

Figure 2. Photographs of van and detector assembly.

VI. System Calibration and Response

Since an available detector had to be used, no choice concerning its size or shape could be made. Several parameters, however, were manipulated to some degree in order to increase the sensitivity of the detector:

A. Detector Orientation - A small radium-226 source was used to check the relative detection efficiency with relation to the detector's vertical axis in order to determine its most efficient position. The source-to-detector axis distance was kept constant and relative count rate measurements were made at 45° angle intervals through 180° (Figure 3). The most efficient source-to-detector position would be the position as indicated by the highest relative count rate as listed in Figure 3. Since the detector was to observe areas to the right side of the transport van, position #3 (i.e., crystal facing downward) was selected for the detector operation although it had approximately 20 percent decrease in efficiency compared to the more favorable positions (#1 and #2). The reasons for not selecting positions #1 and #2 were that possible stresses could be placed upon the crystal assembly from shear forces by the photomultiplier tubes in the horizontal position, and that shielding the detector assembly for these positions would be more difficult.

B. Detector Radiation Shielding - Lead shielding, about 4-cm thick, was placed around the bottom and sides of the detector in order to shield it from terrestrial radiation. A side port was cut in the shielding in order to "view" a typical 107 square meters (10.6 m x 10.6 m) house slab from a distance of 7.6 meters. Although additional shielding would be more desirable, its extra weight would require a heavier detector suspension system and would contribute to the instability of the carrier vehicle.

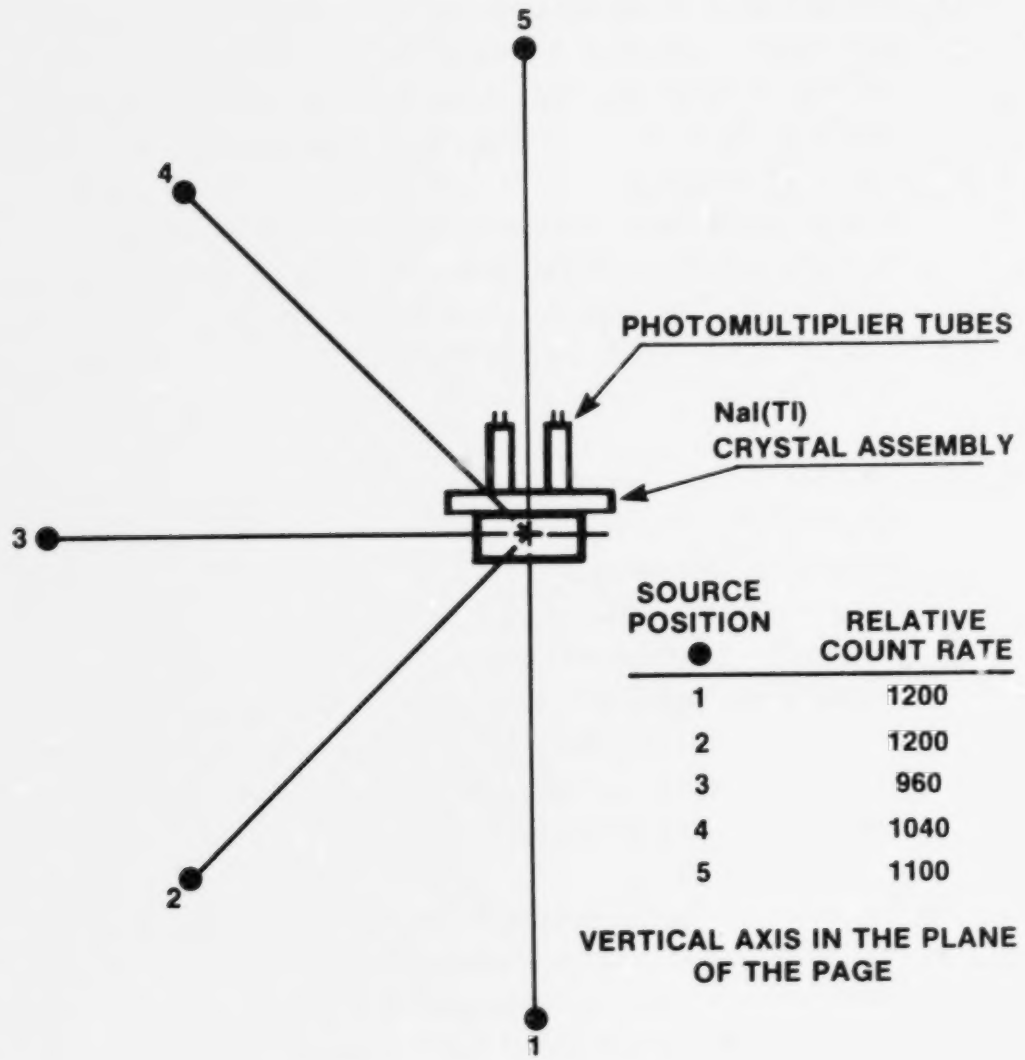


Figure 3. Detector sensitivity versus source position.

C. Energy Response - The gamma ray energy band selected for scanning purposes was from 20 KeV to approximately 0.7 MeV. The lower energy cutoff is due to gamma ray absorption by the aluminum can covering the crystal. The upper limit of 0.7 MeV was selected to eliminate the background count rate from natural potassium-40 contained in the crystal, environment, and structures. The upper energy level is set by slowly opening the single channel window until the count rate exhibites a substantial increase from the 0.66 MeV gamma ray photons from a cesium-137 check source. The window is opened until the count rate becomes constant which indicates that the photo peak is fully contained in the window.

D. Detector Thermal Shielding - Quick temperature changes can cause the detector crystal to fracture. In order to moderate temperature changes, a 2-cm layer of closed-cell plastic foam was placed between the crystal and the lead shielding. The upper part of the crystal assembly was protected with a 3-cm thick plastic foam can. A portable insulated container was constructed to transport and store the crystal when not in use. During cold weather surveys, the carrier van was kept warm overnight by using a catalytic heater.

Figure 4 indicates the response of the detector to an encapsulated radium-226 source which was placed at various distances from and in line with the detector port. The source could be conservatively detected at a distance of 48 meters. With an ambient background of 400 counts per second, a source which produced an exposure rate of 0.34 μR/h at the detector could be measured. Gamma ray exposure rates at curbside were calculated for structures containing uranium mill tailings used for bedding a slab, and for phosphate slag used in concrete walls (Appendix A). The estimated exposure rate at curbside for mill tailings use was approximately 3 μR/h, and that from phosphate slag use was 1 μR/h. These rates would produce count rates of 450 and 150 counts per second above background, respectively.

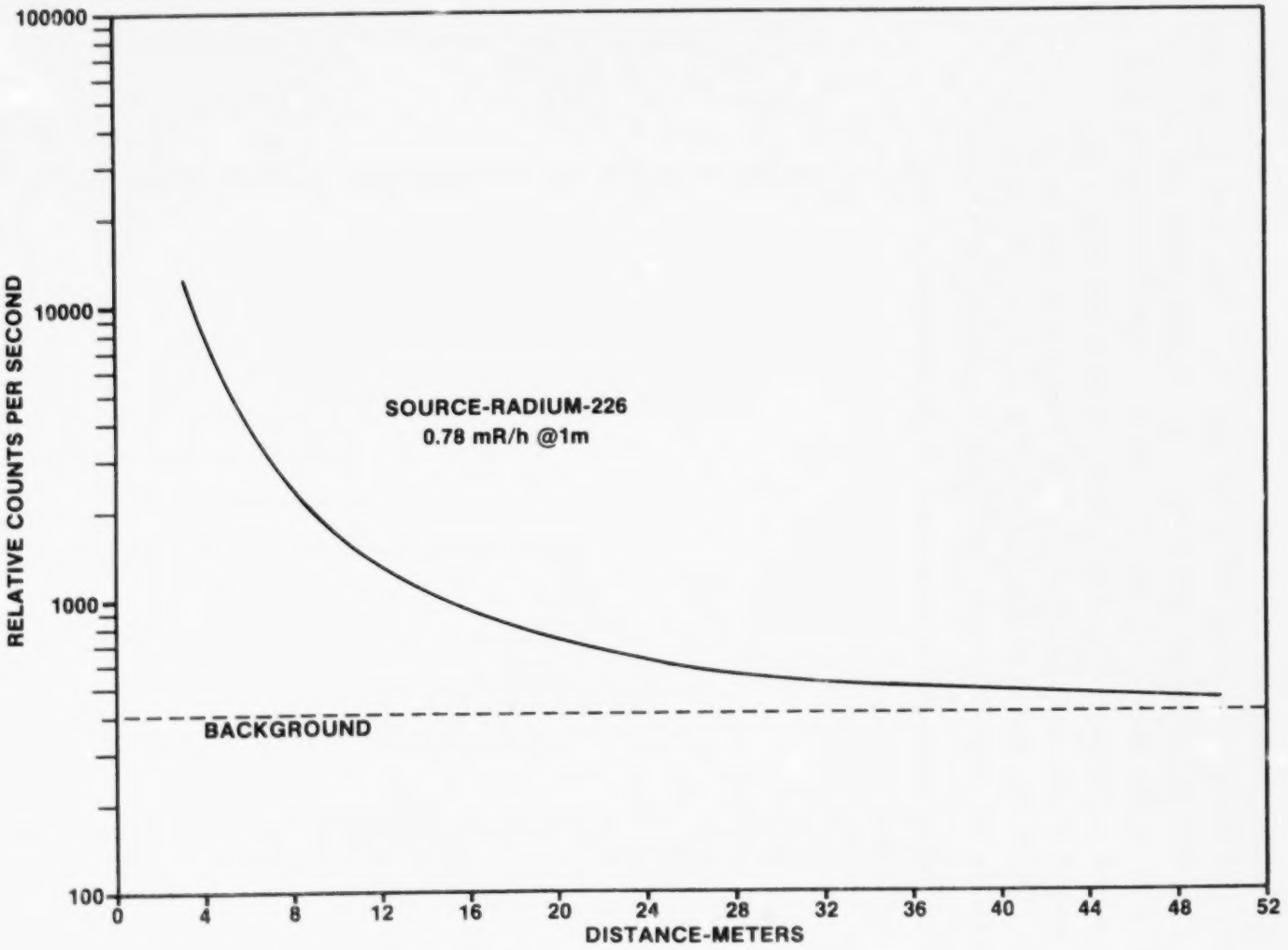


Figure 4. Detector response versus distance from source.

Figure 5 depicts the relative directional response of the detector for four equidistant radium-226 source positions. The source was positioned at the same elevation as the detector for the port, rear, and front measurements. The count rate for the underneath measurement was extrapolated to the same distances (6 m) as the other measurements. Front and rear measurements were about 30 percent of the port measurements and the underneath measurement was about 15 percent of the port measurement. Since the major interfering source (phosphate slag in the road bed) was at ground level, the shielding around the crystal effectively reduced the count rate from this source by 85 percent.

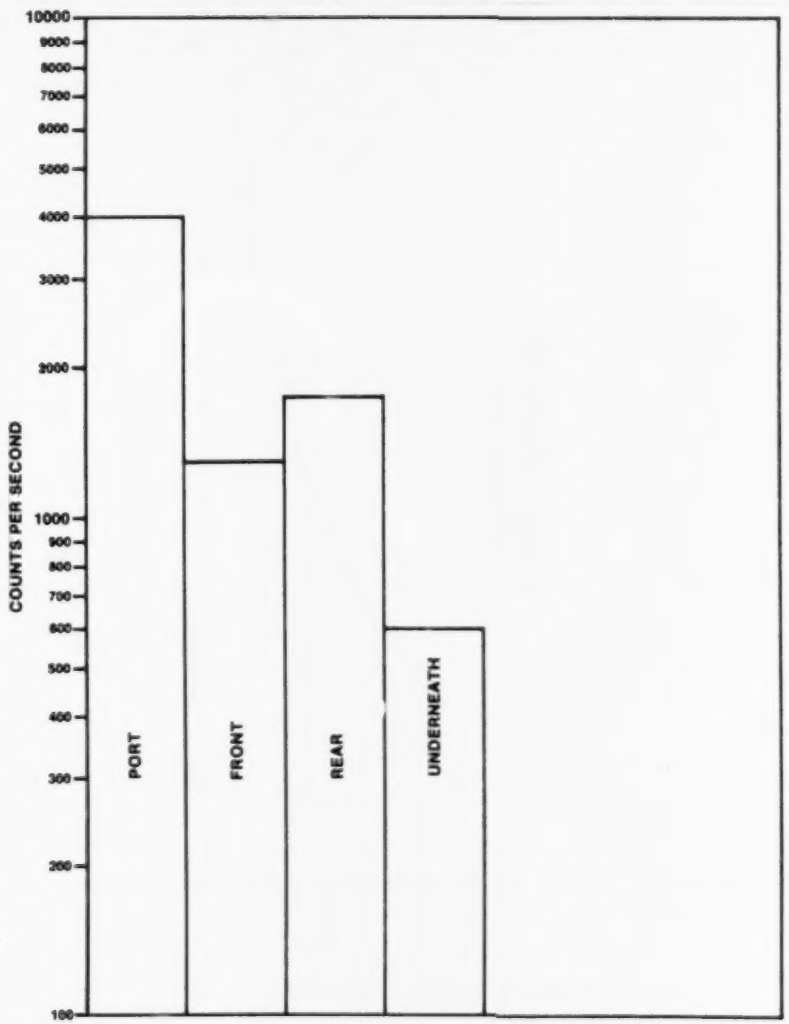


Figure 5. Detector directional response inside van.

GAMMA LOGGING EXPERIENCES

I. Areas Using Phosphate Slag Material

Large quantities of slag material are generated each year as a by-product of the thermal process of the phosphate industry. This slag material is enriched in the naturally-occurring radioactive products of the uranium decay chain series. Table 1 shows the typical radioactive constituents of samples of Idaho phosphate ore and slag materials.

In the past several years, there has been an increasing use in Idaho, Montana and several other states of this slag material for a number of unrestricted construction purposes such as aggregate in concrete and asphalt, roadbed fill, railroad ballast, and stabilization material for stock yards. The most significant use in habitable structures of slag has been for use as "fill" or as aggregate in concrete foundations, sidewalks and driveways.

In general, the phosphate industry is neither regulated nor monitored for the possession, use, or discharge of radioactive materials associated with phosphate rock (ore), its products, or by-products (e.g., slag). Recently, the State of Idaho (June 1, 1977) has prohibited the use of phosphate slag material in the construction of habitable structures only, but has permitted the continued unrestricted use for other purposes. The discharge into waterways of radioactive pollutants has been regulated by specific plant National Pollutant Discharge Elimination System (NPDES) Permits. To date, the airborne discharge of radioactive materials has not been included under the discharge restrictions applicable under the Clean Air Act Amendments.

The following section discusses the use of the mobile sodium iodide crystal detector system to conduct fairly rapid gamma radiation screening surveys to locate structures and areas where phosphate slag has been used. Once the magnitude of this problem has been assessed, more specific surveys

TABLE 1. MAJOR RADIOACTIVE CONSTITUENTS OF IDAHO PHOSPHATE ORE AND SLAG MATERIALS*

Average Radionuclide Concentration ± Two-Sigma Counting Error Term, in pCi/gram

Radionuclide	Pocatello Plant-ORE	Pocatello Plant-SLAG	Soda Springs Plant-ORE	Soda Springs Plant-SLAG
Ra-226	26 ± 19	32 ± 13	47 ± 1.3	50 ± 1.3
U-234	22 ± 2.0	25 ± 6.7	37 ± 3.2	38 ± 8.4
U-235	0.95 ± 0.40	1.1 ± 0.58	1.5 ± 0.48	<1.2
U-238	22 ± 3.2	25 ± 7.0	34 ± 3.0	29 ± 7.0
Th-230	22 ± 4.1	26 ± 11	38 ± 1.3	42 ± 1.5
Th-232	0.43 ± 0.12	0.59 ± 0.29	0.29 ± 0.12	0.48 ± 0.17

* All radiochemical analyses were completed using standard procedures (Johns, 1975) at the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, (EMSL), Las Vegas, NV.

may be conducted at the use sites to better define the radiological impact of phosphate slag utilization.

A. Screening Surveys in Soda Springs, Idaho

Due to the scarcity of economical quantities of natural aggregate materials in the Soda Springs area, phosphate slag has been widely used in the local construction industry during the past ten years. It has been estimated that for the period 1972 to 1974, a total of about 24 curies of radium-226 (one of the major radioactive constituents of phosphate slag) has been redistributed throughout the general environs of the Soda Springs area (Boothe, 1977). The use of the mobile scanner was limited to identifying locations of elevated gamma radiation levels, regardless of the specific use of slag material at that location. Only follow-up surveys using portable instruments will be able to define the exact geometry and intensity of radiation from slag materials incorporated as aggregate in concrete foundations, driveways or sidewalks, or as "fill" material under and around the structure.

The mobile scanner was operated in the Soda Springs area during October 27 to 29, 1977. Figure 6 is a typical portion of the gamma ray log for Soda Springs, Idaho. Areas of possible slag use were observed to produce gamma ray photon peak rates greater than 100 counts per second (cps). Structures presumed to have no phosphate slag use are marked (↓) on the strip chart. The entire community was surveyed and 340 out of 1082 locations (about 31 percent) were reported as having elevated gamma radiation levels. An additional 25 to 30 anomalies were detected in the outlying areas. Background measurements, using a Pressurized Ionization Chamber (PIC) outside the van, averaged about 15 μR/h for this area. Several structures with elevated gamma radiation levels (e.g., a church, hospital, and school) were further surveyed, using portable instruments. Gamma

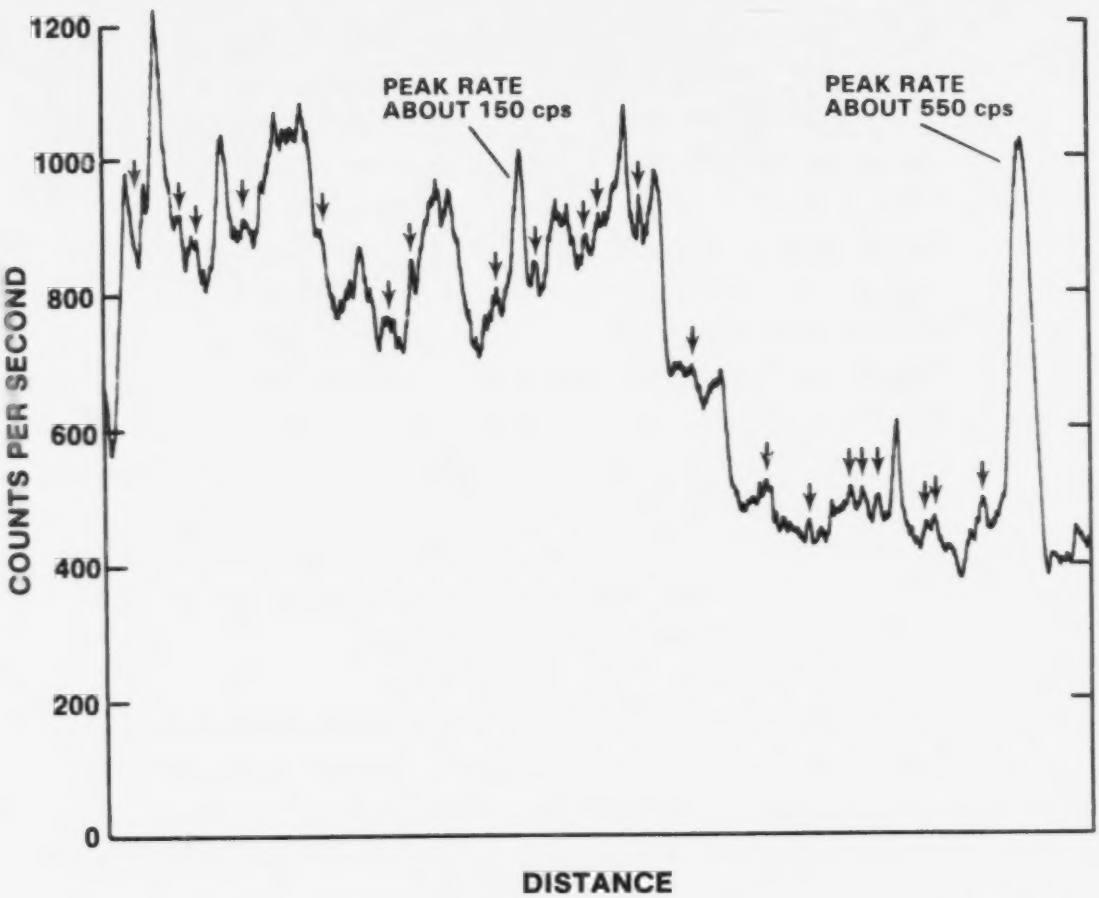


Figure 6. Gamma ray log of streets in Soda Springs, Idaho.

exposure rates as high as 100 μR/h were measured indoors, thereby confirming the mobile scanner results. The shaded areas on the map of Soda Springs, Figure 7, indicate the relative locations of the observed anomalies.

So far, slag has not extensively been incorporated in the pavement or roadbeds but has been used for seal coating. However, it appears that slag has been used as "fill" material in most of the public parking lots and also as fill and/or aggregate material for residential driveways and sidewalks. The most widespread use of slag has been for railroad track ballast and radiation levels up to 100 μR/h were measured, using the scintillometer, at one-meter height over the track right-of-way.

A few locations identified as having used slag in their construction were previously surveyed in 1975. Gamma radiation levels and indoor radon progeny concentration evaluations are reported in Table 2. Of the 340 locations identified by the mobile scanner as having elevated radiation levels, the exact number of habitable structures which utilized slag material as aggregate for concrete foundations or walls, or as land fill under or around the structure, can only be determined by additional follow-up surveys using portable instruments.

Considering the results reported in Table 2 to be representative of the radiological exposure conditions due to the utilization of slag for construction purposes, the following exposure estimates have been made:

1. External Gamma Exposure Estimate

    a. The assumption is made that the exposure rates measured using the scintillator survey meter are equivalent to the "true" gamma exposure rate.

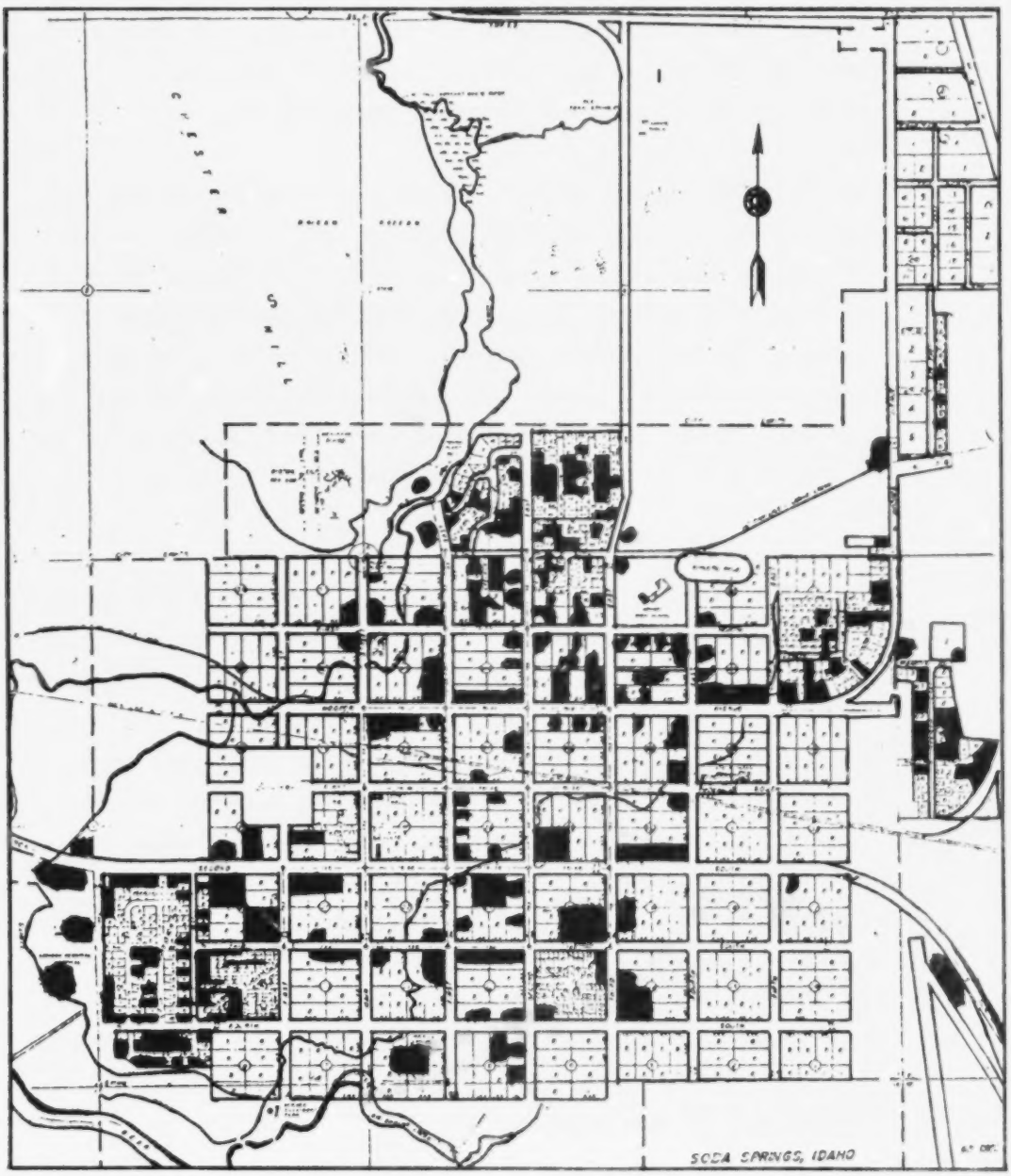


Figure 7. Map of Soda Springs anomalies.

TABLE 2. GAMMA RADIATION AND WORKING LEVEL EVALUATIONS AT SELECTED LOCATIONS IN SODA SPRINGS, IDAHO

Location Description*	Highest Outside Gamma Exposure Rate (μR/h)+	Highest Inside Gamma Exposure Rate (μR/h)+	Sampling Period	Total Hours Sampled	Ambient Radon Progeny Concentration-Average Working Level (Range)++
Residence/non-masonry (Slag used within/under)	30	65	4/21/76 to 9/22/76	1046.5	0.016 (0.014 to 0.018)
Residence/non-masonry (Slag used within/under)	35	50	4/21/76 to 9/7/76	639.7	0.015 (0.0061 to 0.030)
Residence/non-masonry (Slag used under & outside)	45	65	9/23/75 to 4/4/77	2588.7	0.014 (0.0085 to 0.022)
Residence/non-masonry (Slag used within/under)	50	55	4/21/76 to 6/15/77	2689.1	0.010 (0.0045 to 0.017)
Public School (masonry) (Slag used within/under)	30	35	8/12/75 to 6/15/77	3409.3	0.0086(0.00087 to 0.026)
Residence/non-masonry (Slag used outside)	29	10	9/23/75 to 6/15/77	3429.3	0.0086(0.0031 to 0.014)
Residence/non-masonry (Slag used outside)	35	20	4/21/76 to 10/1/76	787.4	0.0058(0.0039 to 0.0069)

* Slag was probably used as concrete aggregate material but may also have been used as fill underneath and around the foundation. Slag used outside probably was for fill or in concrete driveway or sidewalk.

\+ As measured using the Baird-Atomic NE148A- Gamma Scintillator Ratemeter.

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b. The highest gamma exposure rate measured indoors was 65 μR/h.

c. The measured background exposure rate was 15 μR/h (average of outdoor measurements). Therefore, the net gamma exposure rate indoors was about 50 μR/h.

d. The minimum occupancy time for a residence is about 8 hours per day, or 2920 hours per year. The most likely exposure condition would be for a housewife or children occupying the structure on a fairly continuous basis (i.e., exposure times much greater than 2920 hours). A reasonable estimate of the dose equivalence received by an occupant of a structure for the postulated minimum occupancy time is about 140 mrem per year above background (50 μR/h x 2920 h/yr x 10^{-3} mrem/μR) (assuming 1 μR/h = 1 μrem/h).

Hence, it appears that minimum occupancy of structures where slag was used in their construction would not result in an annual dose greater than the recommended guideline of 170 mrem average for the general population (NCRP, 1971). However, the most likely occupancy period would result in an annual dose of about 440 mrem (i.e., 24 h/day x 365 day/yr x 50 μR/h x 10^{-3} mrem/μR). Such a maximum postulated exposure would just be permissible under the provisions of the State of Idaho radiation control regulations (State of Idaho, May 1973); i.e., less than 500 mrem/yr to any individual of the general population.

2. Exposure to Radon Progeny Concentrations

a. The highest measured average working level was 0.016 WL (Table 2).

b. Since all of the dwellings surveyed for indoor concentrations of radon progeny had some slag associated with their construction, the best estimate of the background value would be somewhat less than the lowest measured value of 0.0058 WL (Table 2). However, the value of 0.0058 working level will be used as the background value for Soda Springs.

c. Therefore, an average net radon progeny concentration of 0.01 working levels is possible for structures containing phosphate slag.

A working level of 0.01 is the lower guideline value for possible corrective remedial action for structures having uranium mill tailings associated with their construction (U.S. Surgeon General, 1970). On the assumption that radon-222 and its progeny are present in the structure in ratios 1.0/0.9/0.5/0.35 (for living accommodations with normal ventilation) a working level of 0.01 would correspond to a radon level of 2 pCi/l or about twice the level permissible under the State of Idaho regulations for unrestricted areas (State of Idaho, May 1973). No measurements of radon levels have yet been made in Idaho structures which contain slag.

Several other population exposure pathways also exist due to the "unrestricted" use of phosphate slag material in addition to the increased exposures resulting from occupancy of structures utilizing slag material in their construction. Such pathways have not been evaluated but are mentioned here for future consideration:

1. Increased gamma exposure rate received while driving or walking on streets paved with slag material or while occupying nearby structures.

2. Increased risk of inhalation of fugitive dust containing radioactive particulates from the resuspension of slag materials used for road and driveway construction.

3. Increased risk due to inhalation of radon gas, and its particulate progeny, emanating from slag materials dispersed throughout the environment (e.g., paved roads or railroad track ballast).

In summary, 340 locations in the Soda Springs area (nearly one-third of the structures) were identified as having elevated gamma exposure rates, as compared to a background level of 15 μR/h, using the mobile scanner. To confirm the mobile scanner results, radiation exposure rates up to 100 μR/h were measured indoors, using both the PIC and portable survey instruments at several selected locations. Radon progeny concentrations measured inside a few structures which had elevated gamma exposure rates ranged from 0.0058 to 0.016 working levels. As a result of these preliminary findings, it is recommended that further evaluations of the indoor gamma exposure rates and radon progeny concentrations be completed in order to fully determine the total radiological impact of the use of phosphate slag in the construction of habitable structures in the Soda Springs area.

B. Screening Surveys in Pocatello, Idaho

The major use of phosphate slag in the Pocatello area has been for asphalt mix for paving of streets and parking lots. During 1974, about 15 curies of radium-226 (one of the major radioactive constituents of slag) were redistributed throughout the general environs around Pocatello (Boothe, 1977). Fortunately, there is an abundant supply of natural aggregate material in this area; hence, very little slag has been used as aggregate for concrete in the construction industry. The prime use of

crushed slag on residential lots appears to be for "fill" in driveways. There is also considerable use of crushed slag for farm road construction in the outlying rural areas.

The average background gamma radiation exposure rate, as measured by a Pressurized Ionization Chamber (PIC) at one-meter above ground surface, was 11 μR/h for the Pocatello area. Gamma radiation levels at one-m height above road surfaces were as high as 40 μR/h. One parking lot covered with 7.6 cm (3-in) of crushed slag had a gamma exposure rate of 44 μR/h at a one-meter height. Due to the widespread use of crushed slag for driveway fill, it was impossible, using the mobile scanner, to identify locations where slag was used solely in the construction of the structure.

The mobile scanner was operated in the Pocatello area from October 29 to November 3, 1977, covering approximately 75 percent of the entire city. Almost all of the area west of the railroad tracks (the older section of town) and the few smaller nearby communities (e.g., Chubbuck, Inkom and Cherry Springs) were not surveyed. Figure 8 is a log made in Pocatello on a street that was paved with phosphate slag. The count rate peaks, for the most part, are indicative of a visually confirmed use of phosphate slag outside of structures (driveways, planters, yards, etc.). It was not, however, possible to verify that these locations had not also used slag for construction purposes. The large peaks at both ends of the log were caused by crossing an intersecting street that was paved with phosphate slag. Figure 9 shows a typical log from a street having no slag use or any visible slag around the structures. The variation in the log's count rate trace was less than 50 counts per second. Figure 10 contains a portion of the Pocatello log made in the downtown area. The peaks are generally larger than those caused by residences and, for the most part, are due to parking lots which were paved or gravelled with phosphate slag.

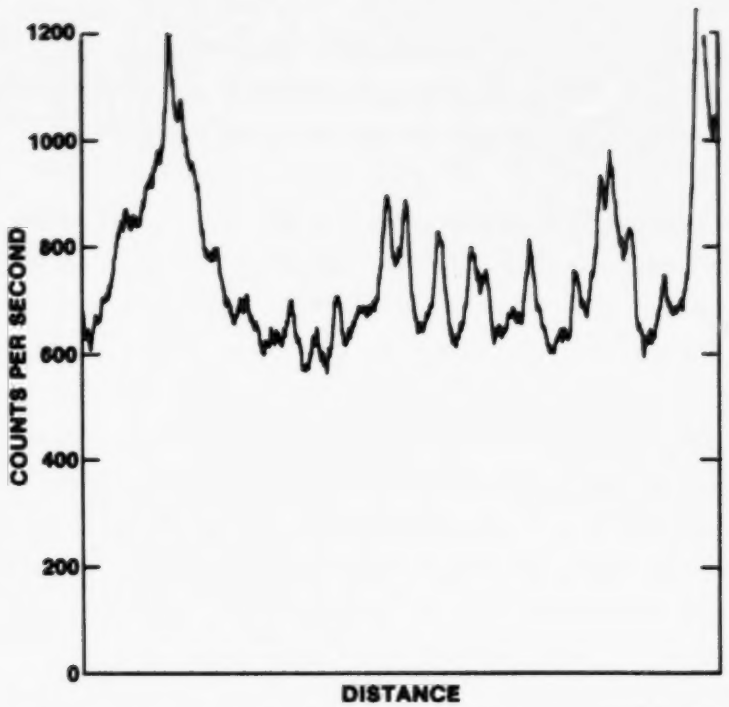

Figure 8. Gamma ray log from Pocatello, Idaho (Street paved with slag).

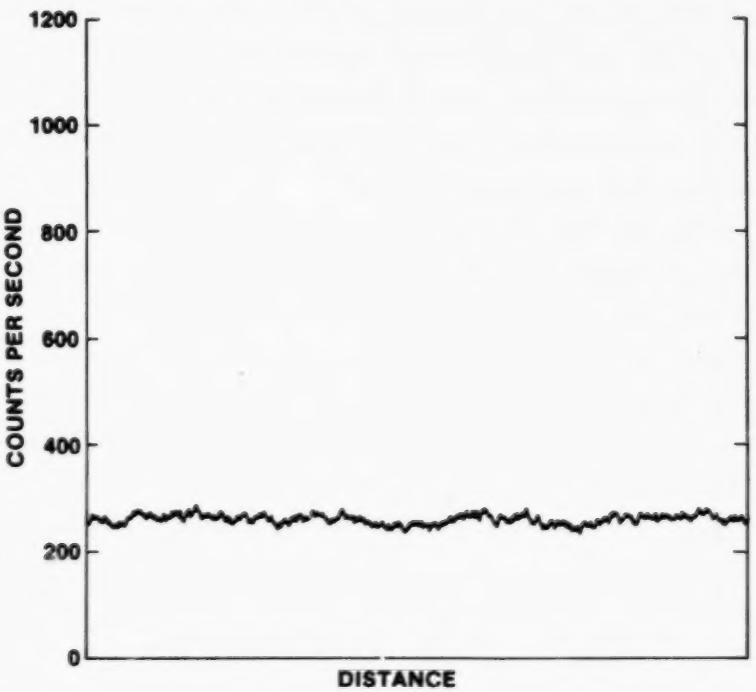

Figure 9. Gamma ray log from Pocatello, Idaho (Street not paved with slag).

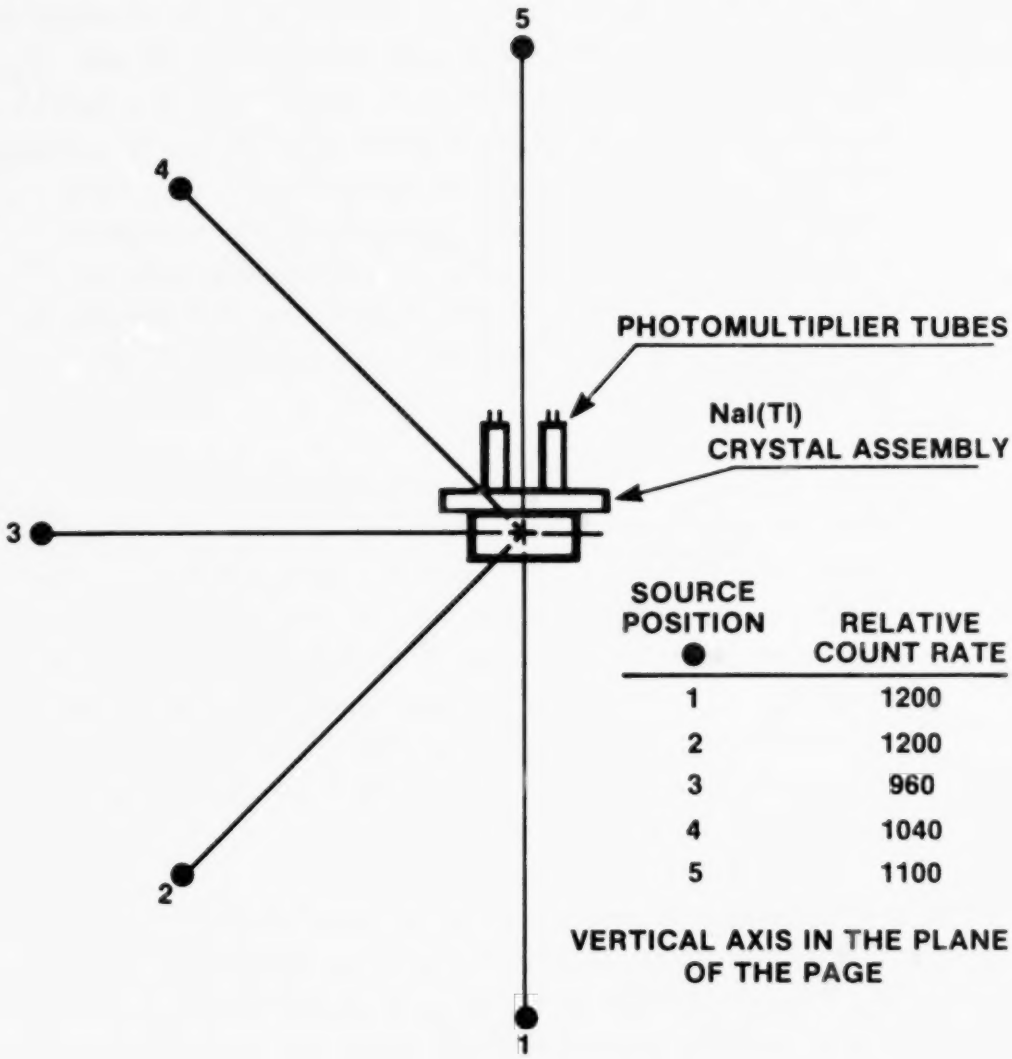

Figure 3. Detector sensitivity versus source position.

C. Energy Response - The gamma ray energy band selected for scanning purposes was from 20 KeV to approximately 0.7 MeV. The lower energy cutoff is due to gamma ray absorption by the aluminum can covering the crystal. The upper limit of 0.7 MeV was selected to eliminate the background count rate from natural potassium-40 contained in the crystal, environment, and structures. The upper energy level is set by slowly opening the single channel window until the count rate exhibites a substantial increase from the 0.66 MeV gamma ray photons from a cesium-137 check source. The window is opened until the count rate becomes constant which indicates that the photo peak is fully contained in the window.

D. Detector Thermal Shielding - Quick temperature changes can cause the detector crystal to fracture. In order to moderate temperature changes, a 2-cm layer of closed-cell plastic foam was placed between the crystal and the lead shielding. The upper part of the crystal assembly was protected with a 3-cm thick plastic foam can. A portable insulated container was constructed to transport and store the crystal when not in use. During cold weather surveys, the carrier van was kept warm overnight by using a catalytic heater.

Figure 4 indicates the response of the detector to an encapsulated radium-226 source which was placed at various distances from and in line with the detector port. The source could be conservatively detected at a distance of 48 meters. With an ambient background of 400 counts per second, a source which produced an exposure rate of 0.34 μR/h at the detector could be measured. Gamma ray exposure rates at curbside were calculated for structures containing uranium mill tailings used for bedding a slab, and for phosphate slag used in concrete walls (Appendix A). The estimated exposure rate at curbside for mill tailings use was approximately 3 μR/h, and that from phosphate slag use was 1 μR/h. These rates would produce count rates of 450 and 150 counts per second above background, respectively.

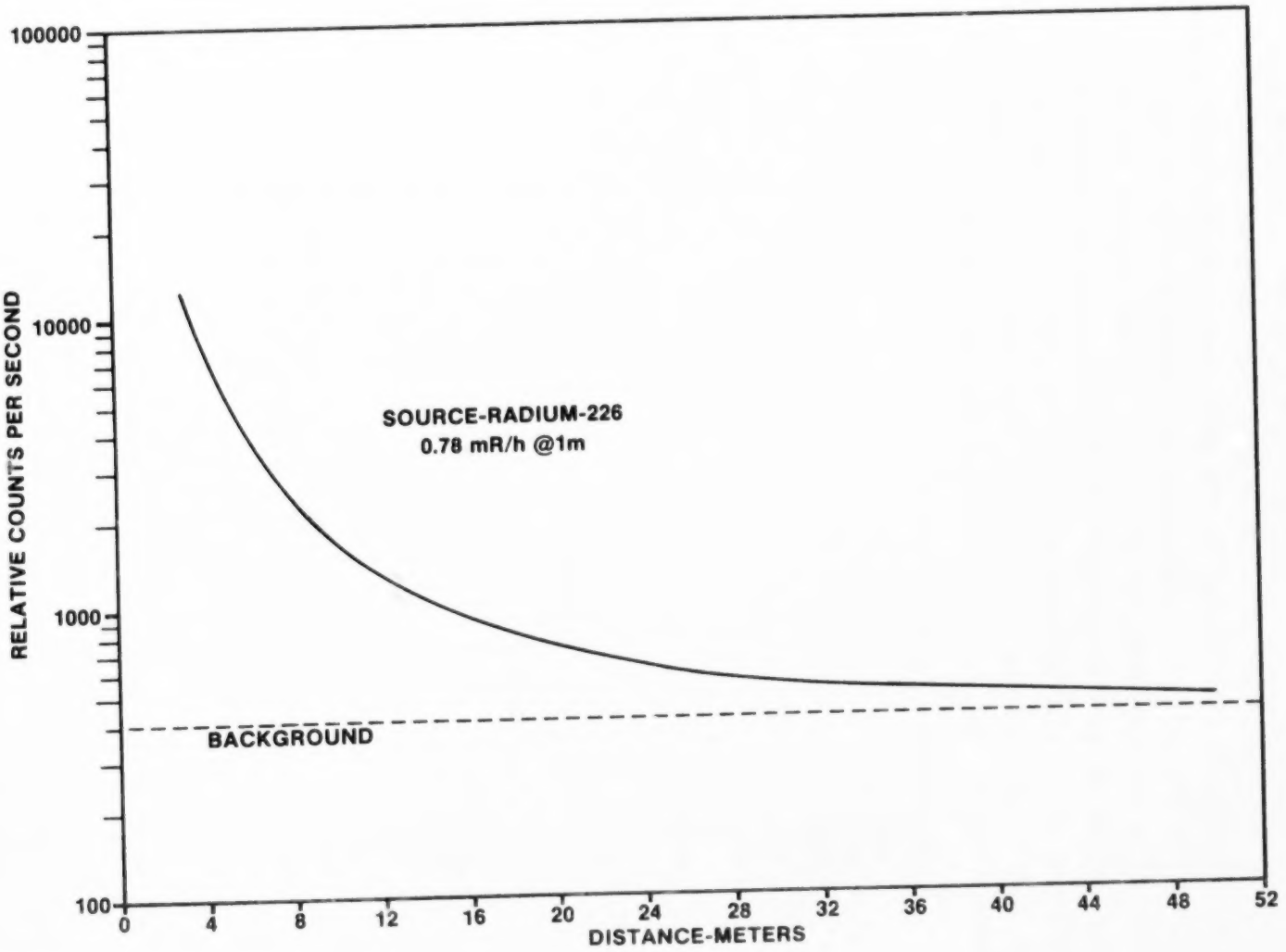

Figure 4. Detector response versus distance from source.

Figure 5 depicts the relative directional response of the detector for four equidistant radium-226 source positions. The source was positioned at the same elevation as the detector for the port, rear, and front measurements. The count rate for the underneath measurement was extrapolated to the same distances (6 m) as the other measurements. Front and rear measurements were about 30 percent of the port measurements and the underneath measurement was about 15 percent of the port measurement. Since the major interfering source (phosphate slag in the road bed) was at ground level, the shielding around the crystal effectively reduced the count rate from this source by 85 percent.

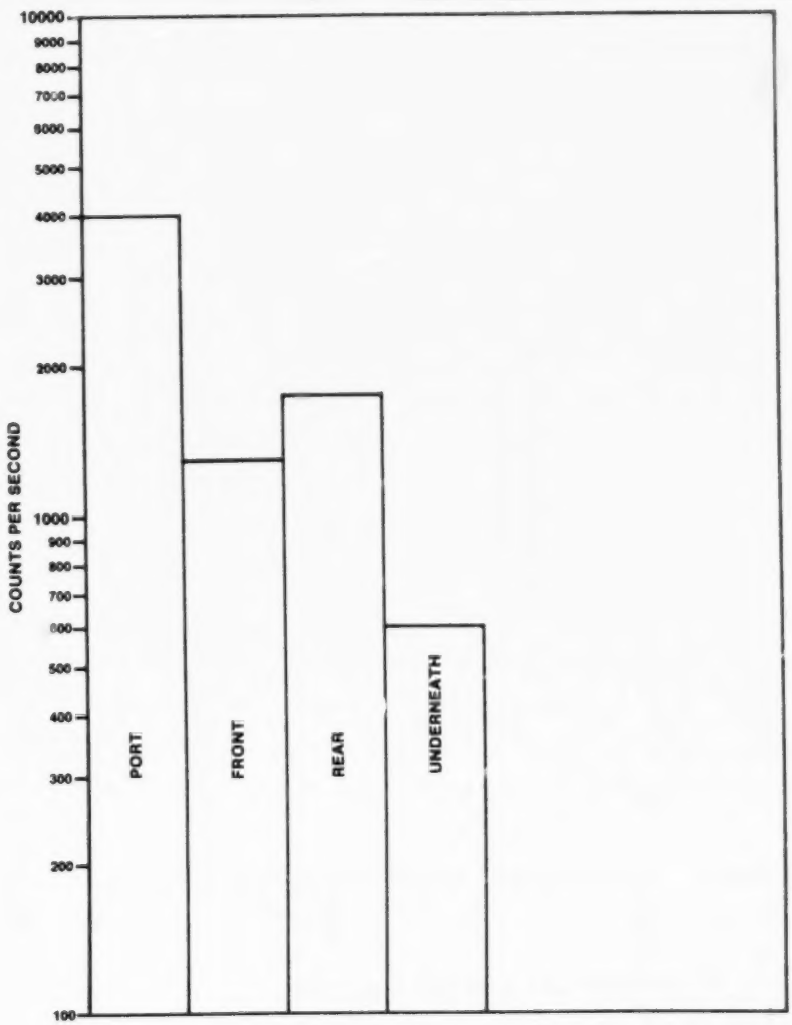

Figure 5. Detector directional response inside van.

GAMMA LOGGING EXPERIENCES

I. Areas Using Phosphate Slag Material

Large quantities of slag material are generated each year as a by-product of the thermal process of the phosphate industry. This slag material is enriched in the naturally-occurring radioactive products of the uranium decay chain series. Table 1 shows the typical radioactive constituents of samples of Idaho phosphate ore and slag materials.

In the past several years, there has been an increasing use in Idaho, Montana and several other states of this slag material for a number of unrestricted construction purposes such as aggregate in concrete and asphalt, roadbed fill, railroad ballast, and stabilization material for stock yards. The most significant use in habitable structures of slag has been for use as "fill" or as aggregate in concrete foundations, sidewalks and driveways.

In general, the phosphate industry is neither regulated nor monitored for the possession, use, or discharge of radioactive materials associated with phosphate rock (ore), its products, or by-products (e.g., slag). Recently, the State of Idaho (June 1, 1977) has prohibited the use of phosphate slag material in the construction of habitable structures only, but has permitted the continued unrestricted use for other purposes. The discharge into waterways of radioactive pollutants has been regulated by specific plant National Pollutant Discharge Elimination System (NPDES) Permits. To date, the airborne discharge of radioactive materials has not been included under the discharge restrictions applicable under the Clean Air Act Amendments.

The following section discusses the use of the mobile sodium iodide crystal detector system to conduct fairly rapid gamma radiation screening surveys to locate structures and areas where phosphate slag has been used. Once the magnitude of this problem has been assessed, more specific surveys

TABLE 1. MAJOR RADIOACTIVE CONSTITUENTS OF IDAHO PHOSPHATE ORE AND SLAG MATERIALS*

Average Radionuclide Concentration ± Two-Sigma Counting Error Term, in pCi/gram

Radionuclide	Pocatello Plant-ORE	Pocatello Plant-SLAG	Soda Springs Plant-ORE	Soda Springs Plant-SLAG
Ra-226	26 ± 19	32 ± 13	47 ± 1.3	50 ± 1.3
U-234	22 ± 2.0	25 ± 6.7	37 ± 3.2	38 ± 8.4
U-235	0.95 ± 0.40	1.1 ± 0.58	1.5 ± 0.48	<1.2
U-238	22 ± 3.2	25 ± 7.0	34 ± 3.0	29 ± 7.0
Th-230	22 ± 4.1	26 ± 11	38 ± 1.3	42 ± 1.5
Th-232	0.43 ± 0.12	0.59 ± 0.29	0.29 ± 0.12	0.48 ± 0.17

* All radiochemical analyses were completed using standard procedures (Johns, 1975) at the U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, (EMSL), Las Vegas, NV.

may be conducted at the use sites to better define the radiological impact of phosphate slag utilization.

A. Screening Surveys in Soda Springs, Idaho

Due to the scarcity of economical quantities of natural aggregate materials in the Soda Springs area, phosphate slag has been widely used in the local construction industry during the past ten years. It has been estimated that for the period 1972 to 1974, a total of about 24 curies of radium-226 (one of the major radioactive constituents of phosphate slag) has been redistributed throughout the general environs of the Soda Springs area (Boothe, 1977). The use of the mobile scanner was limited to identifying locations of elevated gamma radiation levels, regardless of the specific use of slag material at that location. Only follow-up surveys using portable instruments will be able to define the exact geometry and intensity of radiation from slag materials incorporated as aggregate in concrete foundations, driveways or sidewalks, or as "fill" material under and around the structure.

The mobile scanner was operated in the Soda Springs area during October 27 to 29, 1977. Figure 6 is a typical portion of the gamma ray log for Soda Springs, Idaho. Areas of possible slag use were observed to produce gamma ray photon peak rates greater than 100 counts per second (cps). Structures presumed to have no phosphate slag use are marked (↓) on the strip chart. The entire community was surveyed and 340 out of 1082 locations (about 31 percent) were reported as having elevated gamma radiation levels. An additional 25 to 30 anomalies were detected in the outlying areas. Background measurements, using a Pressurized Ionization Chamber (PIC) outside the van, averaged about 15 μR/h for this area. Several structures with elevated gamma radiation levels (e.g., a church, hospital, and school) were further surveyed, using portable instruments. Gamma

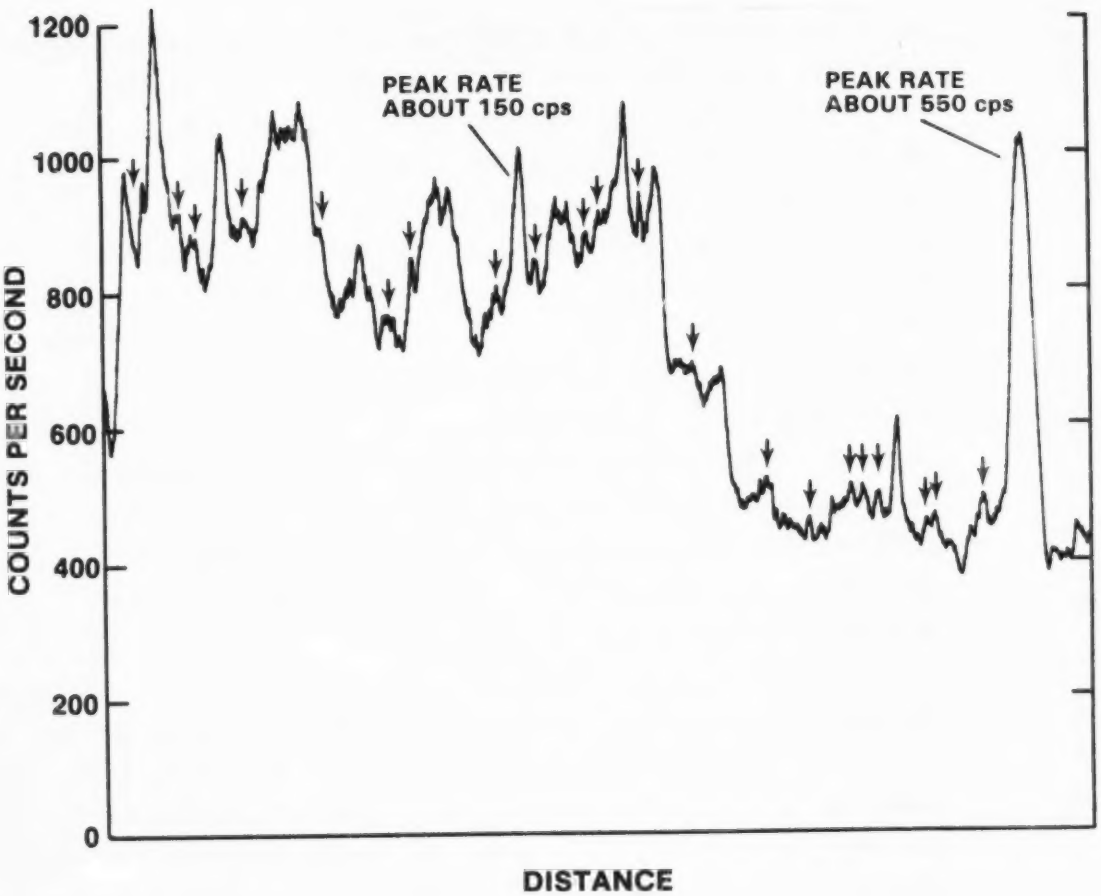

Figure 6. Gamma ray log of streets in Soda Springs, Idaho.

exposure rates as high as 100 μR/h were measured indoors, thereby confirming the mobile scanner results. The shaded areas on the map of Soda Springs, Figure 7, indicate the relative locations of the observed anomalies.

So far, slag has not extensively been incorporated in the pavement or roadbeds but has been used for seal coating. However, it appears that slag has been used as "fill" material in most of the public parking lots and also as fill and/or aggregate material for residential driveways and sidewalks. The most widespread use of slag has been for railroad track ballast and radiation levels up to 100 μR/h were measured, using the scintillometer, at one-meter height over the track right-of-way.

A few locations identified as having used slag in their construction were previously surveyed in 1975. Gamma radiation levels and indoor radon progeny concentration evaluations are reported in Table 2. Of the 340 locations identified by the mobile scanner as having elevated radiation levels, the exact number of habitable structures which utilized slag material as aggregate for concrete foundations or walls, or as land fill under or around the structure, can only be determined by additional follow-up surveys using portable instruments.

Considering the results reported in Table 2 to be representative of the radiological exposure conditions due to the utilization of slag for construction purposes, the following exposure estimates have been made:

1. External Gamma Exposure Estimate

    a. The assumption is made that the exposure rates measured using the scintillator survey meter are equivalent to the "true" gamma exposure rate.

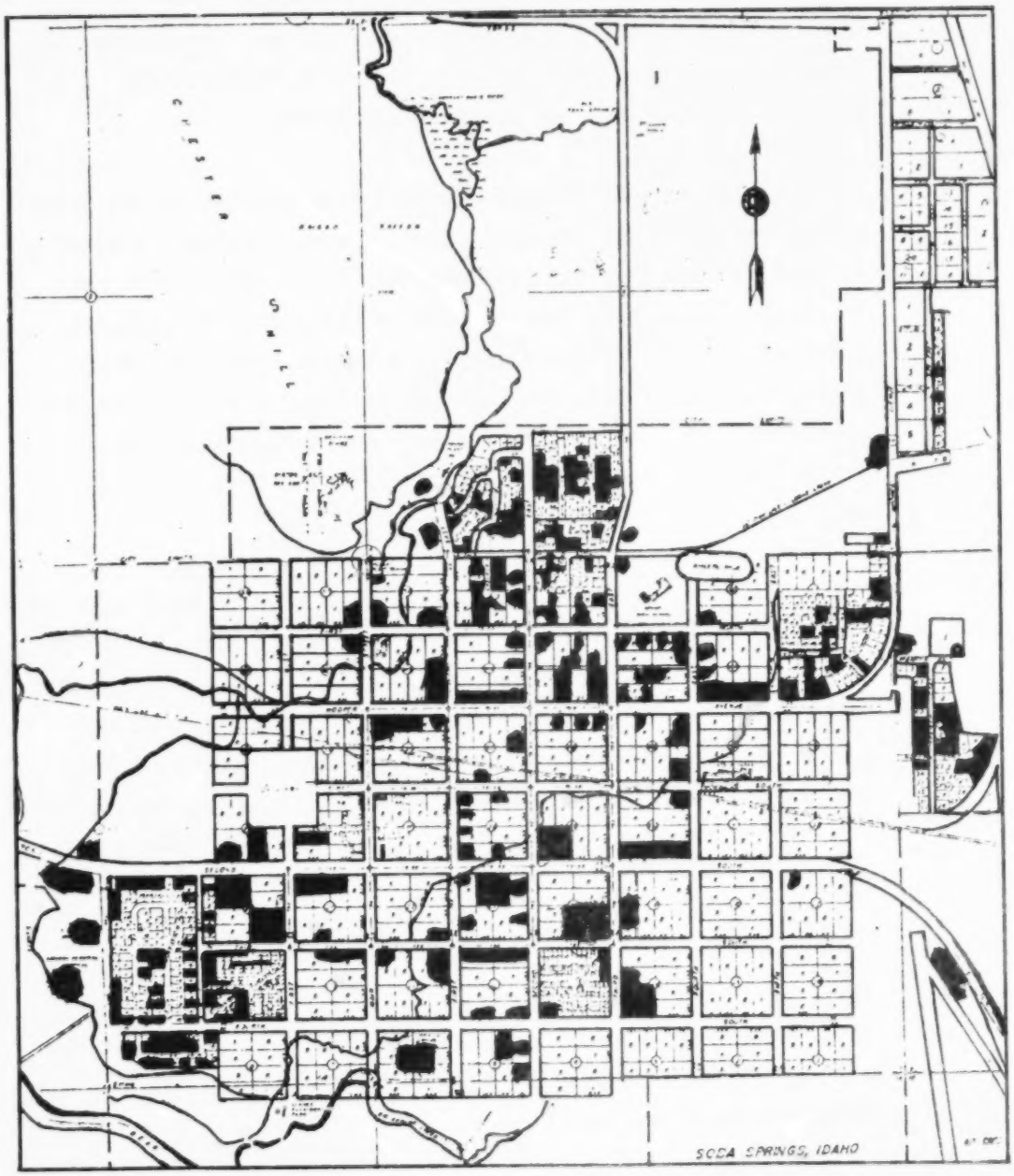

Figure 7. Map of Soda Springs anomalies.

TABLE 2. GAMMA RADIATION AND WORKING LEVEL EVALUATIONS AT SELECTED LOCATIONS IN SODA SPRINGS, IDAHO

Location Description*	Highest Outside Gamma Exposure Rate (μR/h)+	Highest Inside Gamma Exposure Rate (μR/h)+	Sampling Period	Total Hours Sampled	Ambient Radon Progeny Concentration-Average Working Level (Range)++
Residence/non-masonry (Slag used within/under)	30	65	4/21/76 to 9/22/76	1046.5	0.016 (0.014 to 0.018)
Residence/non-masonry (Slag used within/under)	35	50	4/21/76 to 9/7/76	639.7	0.015 (0.0061 to 0.030)
Residence/non-masonry (Slag used under & outside)	45	65	9/23/75 to 4/4/77	2588.7	0.014 (0.0085 to 0.022)
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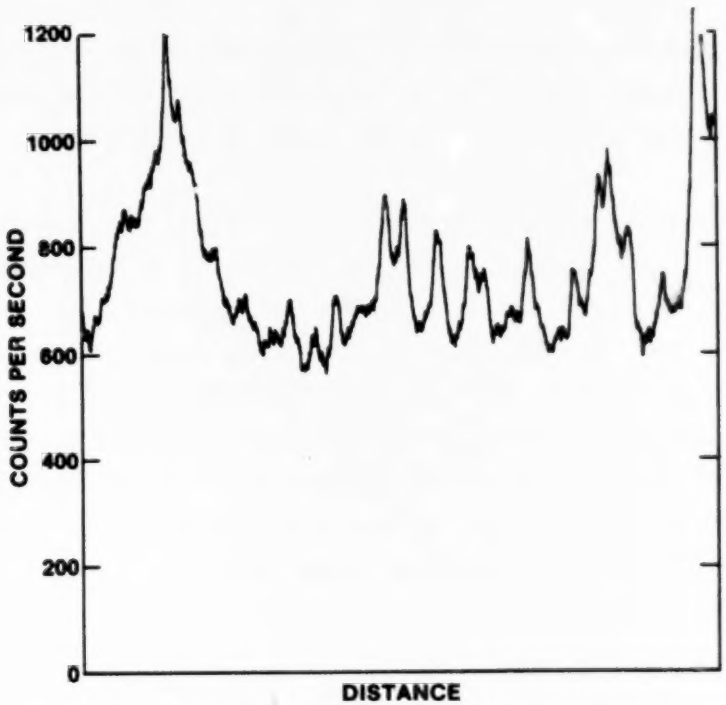

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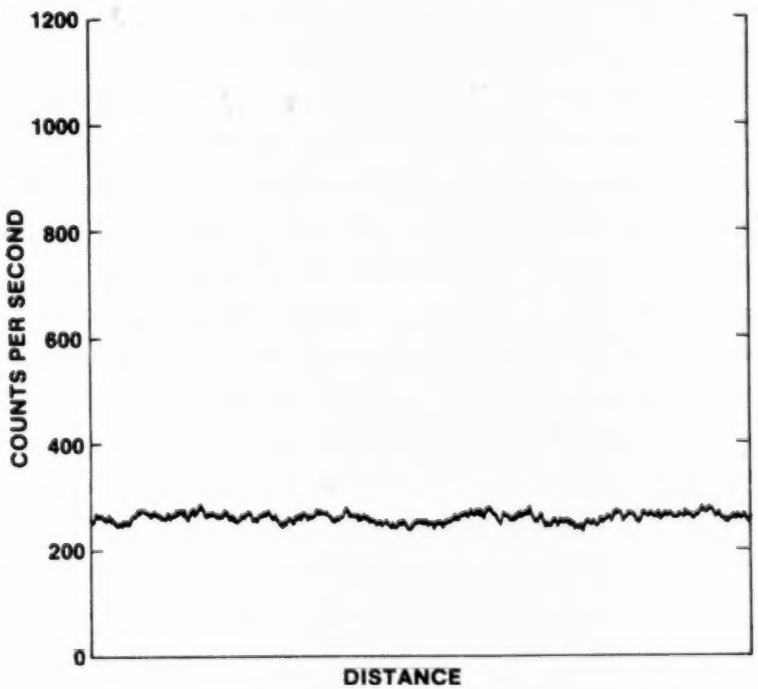

Figure 9. Gamma ray log from Pocatello, Idaho (Street not paved with slag).

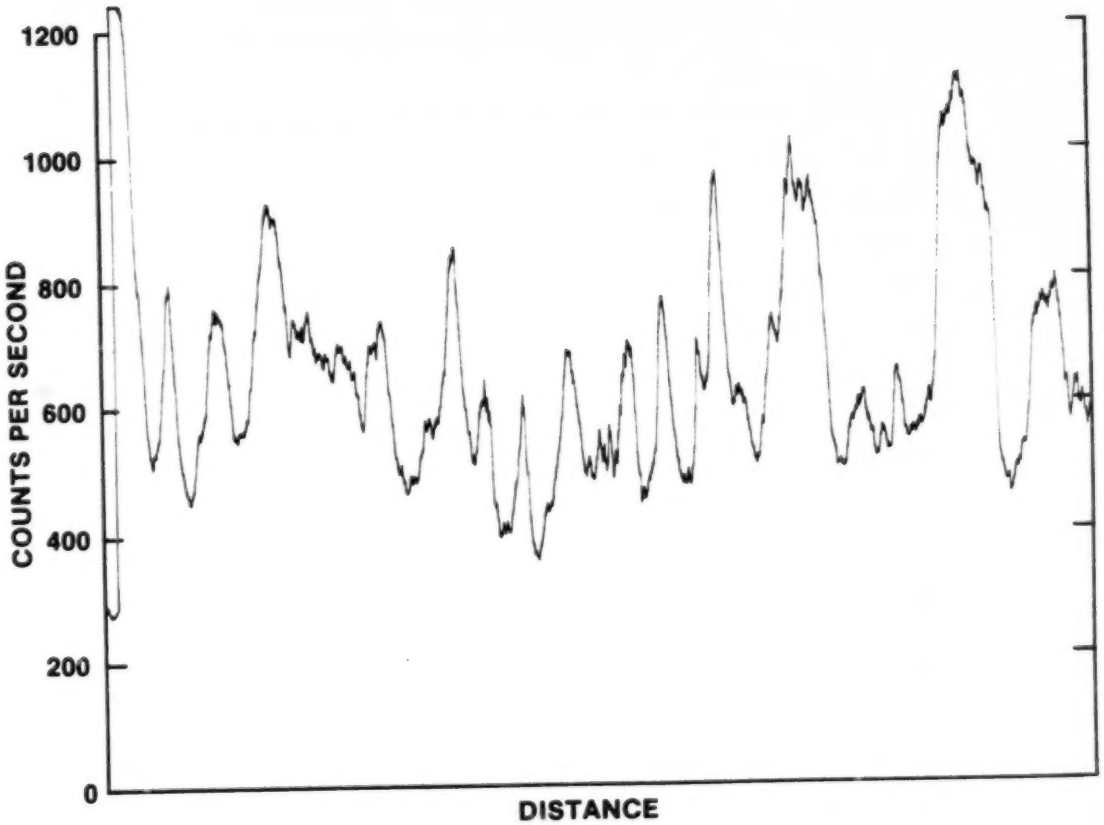

Figure 10. Gamma ray log of downtown Pocatello, Idaho.

Elevated gamma radiation levels were reported for 1550 locations in those areas which were surveyed; however, the vast majority of these locations had slag fill driveways. A total of 2000 to 2250 anomalies has been projected for the Pocatello area. To date, an extensive evaluation of indoor concentrations of radon progeny has not been undertaken in the Pocatello area.

In summary, because of the widespread use of phosphate slag material in the Pocatello area for street pavement mix and for driveway fill, the exact identification of structures built on or with slag cannot be resolved by using the mobile gamma scanner. Additional radiation surveys using portable survey instruments must be completed in order to obtain this information. Therefore, it is recommended that the radiological evaluation of those structures built on or with slag which have already been identified in the Soda Springs area should be completed first. Then, if conditions warrant, further radiological evaluations should be completed in Pocatello and nearby communities.

Until all aspects of the radiological impact of slag utilization have been completed, it is also recommended that the "prohibited use" of phosphate slag in the construction of habitable structures should remain in effect (State of Idaho, June 1, 1977). The continued use of slag material for road construction, railroad ballast, and for other outdoor construction purposes, results in the annual dispersal throughout the general environs of curie quantities of long-lived natural radioactive materials (e.g., radium, uranium, and thorium). Such a situation is creating radiological and environmental risks which will be extremely difficult to evaluate or to rectify in the future. Therefore, the extension of the "temporary use approval" for other construction purposes should be reconsidered. The use of slag for purposes such as discussed above is also known to be taking place in Twin Falls, Idaho; Butte, Montana; and in several other communities in both States.

II. Areas Using Uranium Mill Tailings and Other Miscellaneous Sources

A. Salt Lake City, Utah

While enroute to Idaho, the logging equipment was checked in Salt Lake City, Utah. Figure 11 is a portion of the gamma ray log made in the city's downtown area. The peaks were presumed to be caused by the massive highrise buildings which emitted radiation down through the unshielded top of the detector system. Figure 12 is a portion of the gamma ray log which was made near the former Vitro uranium mill tailings pile located in the southern portion of the city. Three apparent tailings locations are indicated on this log section. An overpass, which is also labelled, appears to have some tailings use.

B. Farmington, New Mexico

Pumice, produced from open pits northwest of Santa Fe, New Mexico, is widely used throughout the southwest as a lightweight aggregate for making cement blocks. The pumice contains about 6 pCi/g of radium-226. After it is mixed with other materials to form the blocks, the average radium concentration in the blocks ranges from 2 to 3 pCi/g. Figure 13 contains a gamma ray log of downtown Farmington, New Mexico and a motel known to contain pumice in the construction block. Two peaks are indicated for the motel because it was passed with the scanner twice in a short period of time. The cause of the three peaks in the downtown section was not verified, however, it is presumed that they were caused by pumice block also.

C. Shiprock, New Mexico

Shiprock, New Mexico contains pumice block from the Farmington, New Mexico area as well as an inactive uranium mill site and a former uranium ore-buying station. Figure 14 contains a gamma ray log of a community building containing pumice block. The three peaks on the log were caused by driving past three different sides of the building. Figure 15 is a log of the

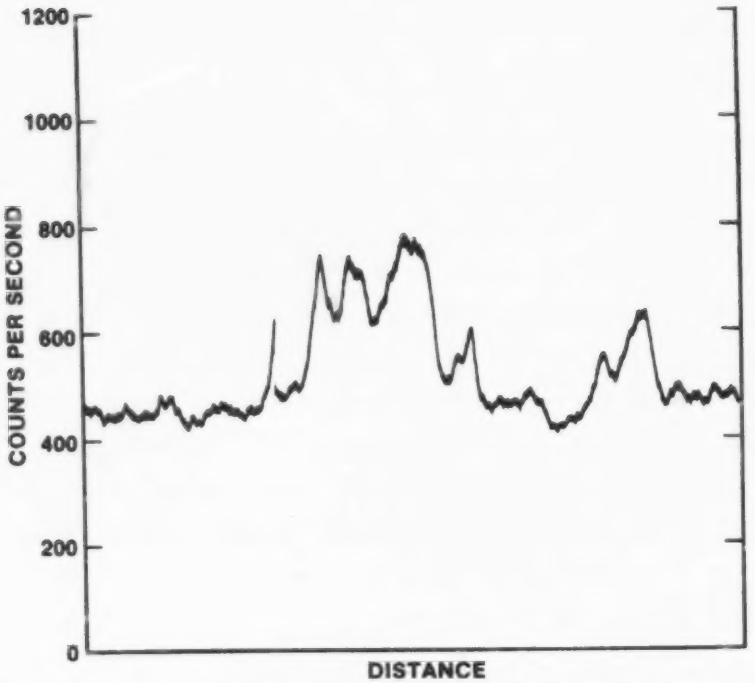

Figure 11. Gamma ray log of downtown Salt Lake City, Utah.

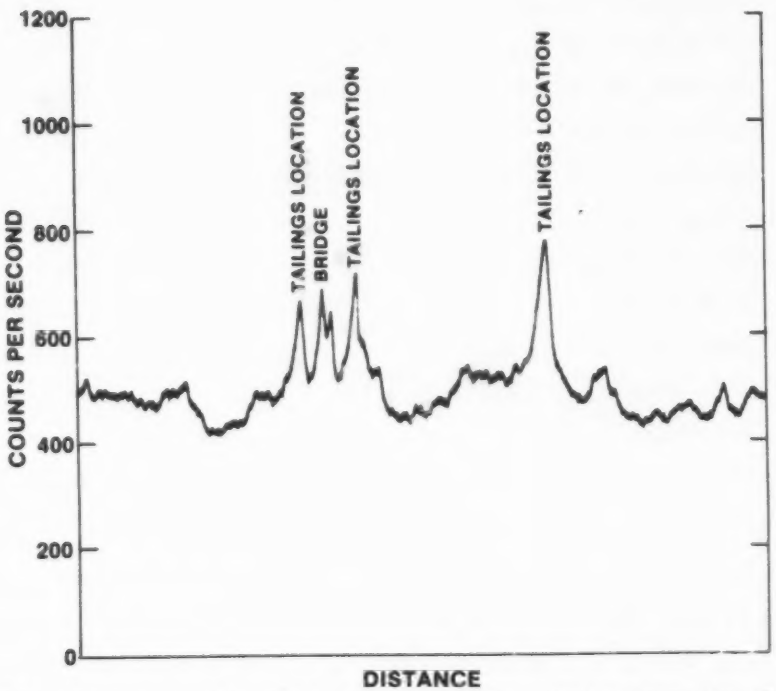

Figure 12. Gamma ray log of Salt Lake City, Utah (Near the former Vitro Uranium Mill Site).

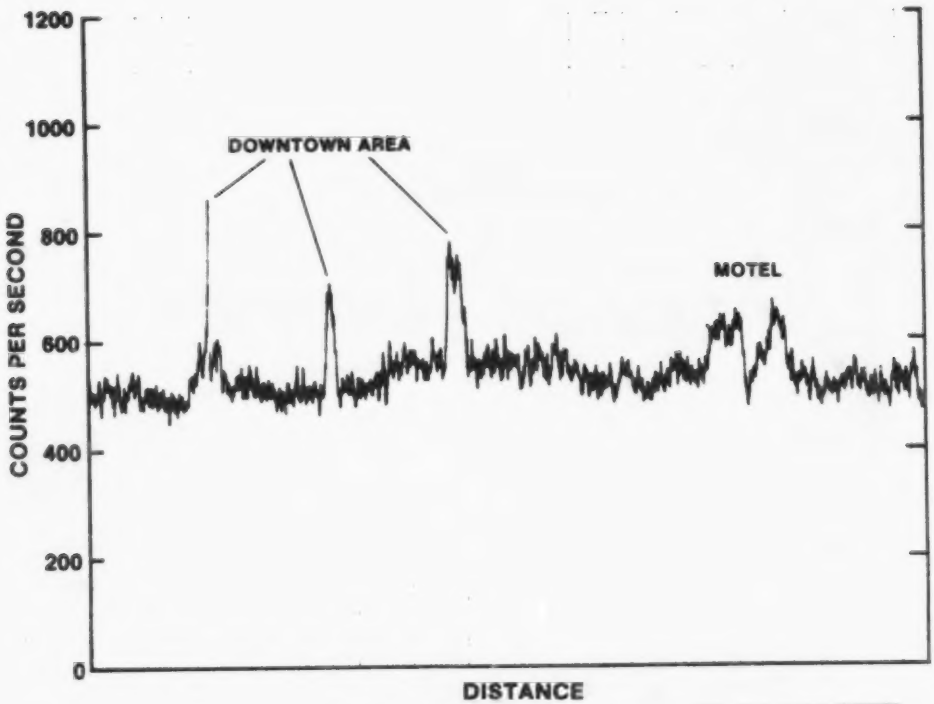

Figure 13. Gamma ray log of Farmington, New Mexico.

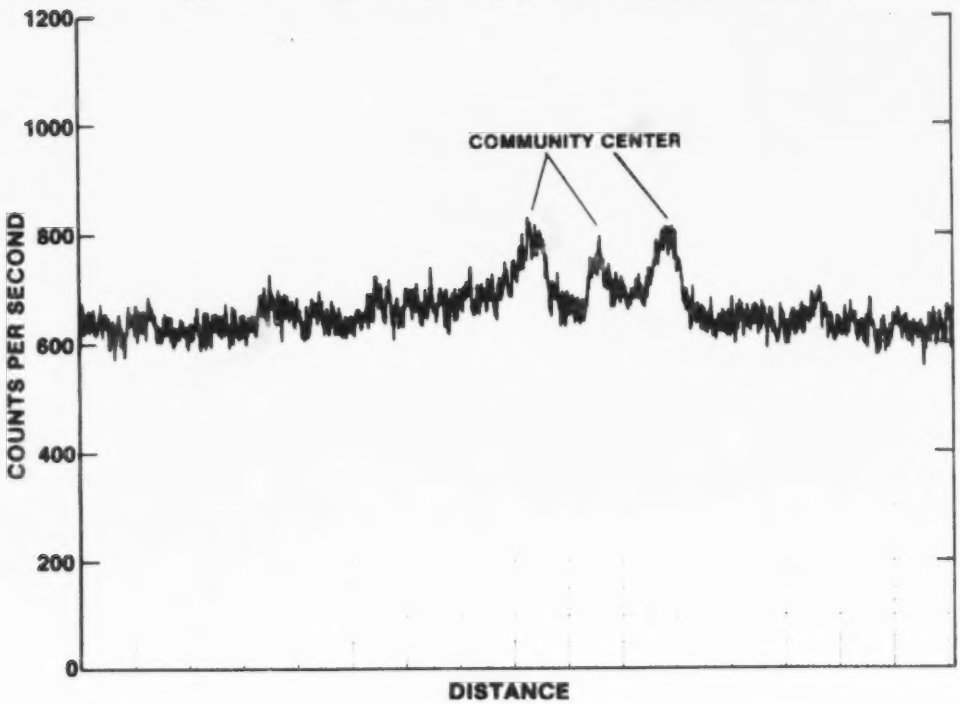

Figure 14. Gamma ray log of Shiprock, New Mexico (Community Center).

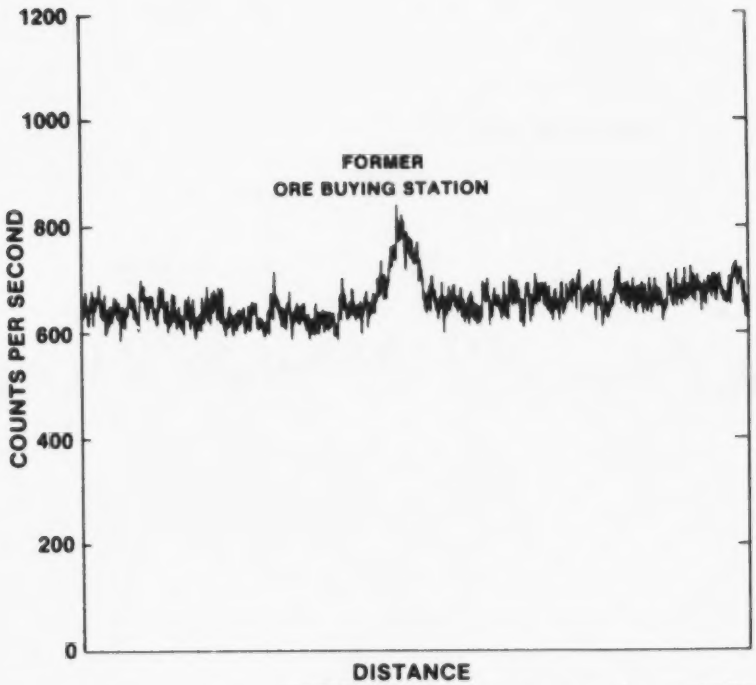

Figure 15. Gamma ray log of Shiprock, New Mexico (Former uranium ore buying station).

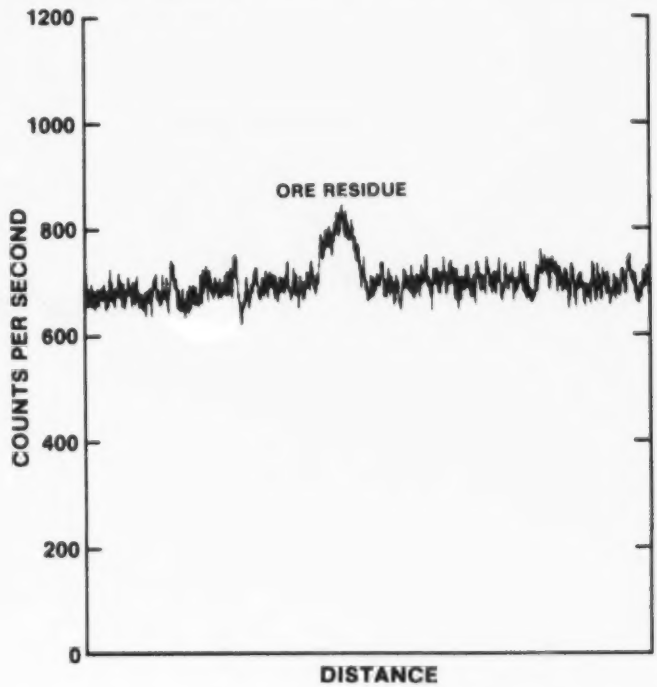

Figure 16. Gamma ray log of Shiprock, New Mexico (Uranium ore residue).

former ore-buying station. The peak is well pronounced although the scanner to source distance was approximately 46 meters. Figure 16 is a log of an area on which uranium ore was dumped because of an ore truck breakdown. The ore was later picked up, leaving no visible residue but apparently some contamination.

D. Miscellaneous Logs

Figure 17 contains three large well-defined peaks caused by propane trucks passing the scanner vehicle. Figure 18 is a gamma ray log made in Gallup, New Mexico. The large peak on this log was presumed to be caused by a large propane tank on a service station lot.

Figure 19 is a portion of the gamma ray log that was made along Interstate 15 from Salt Lake City to the Nevada border. It was noted that the gamma ray background exposure rate increased from about 12 μR/hr to about 23 μR/h around the Cove Fort to the Beaver exit area in Utah. The scanning vehicle was driven off the highway onto a dirt road in order to confirm that the elevated exposure rate did not originate from the highway. Uncorrected pressurized ion chamber exposure rates, location points, peaks caused from highway cuts are also noted on the log. A scale change was necessary midway through the portion of the log in order to plot the higher count rates experienced. A similar anomaly was observed to occur 48 kilometers east of Kingman, Arizona. No explanation for the occurrence of these anomalies can be made except to postulate that they were caused by natural radioactivity.

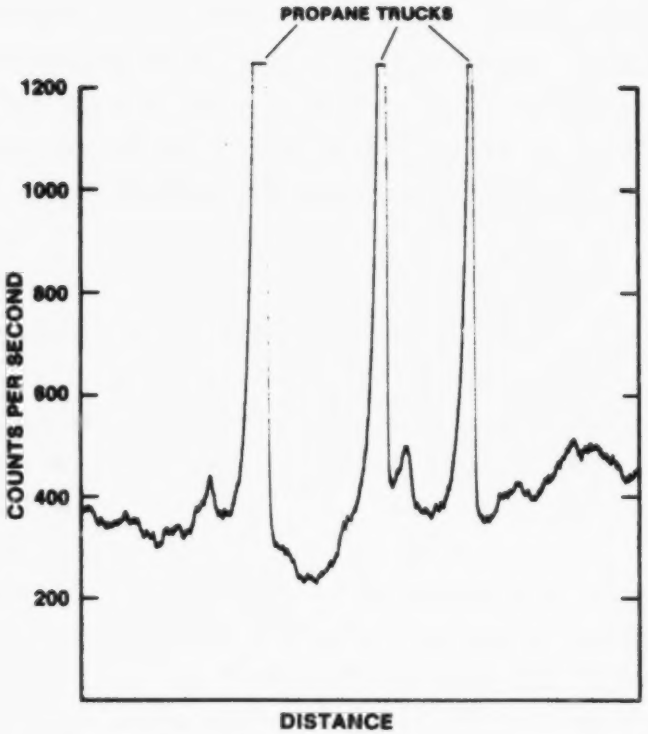

Figure 17. Gamma ray log from propane trucks.

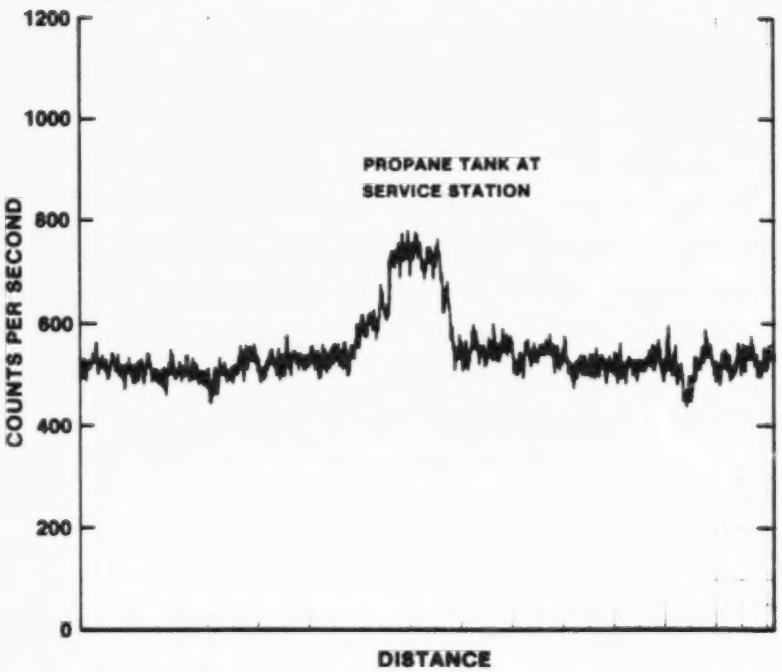

Figure 18. Gamma ray log from Gallup, New Mexico.

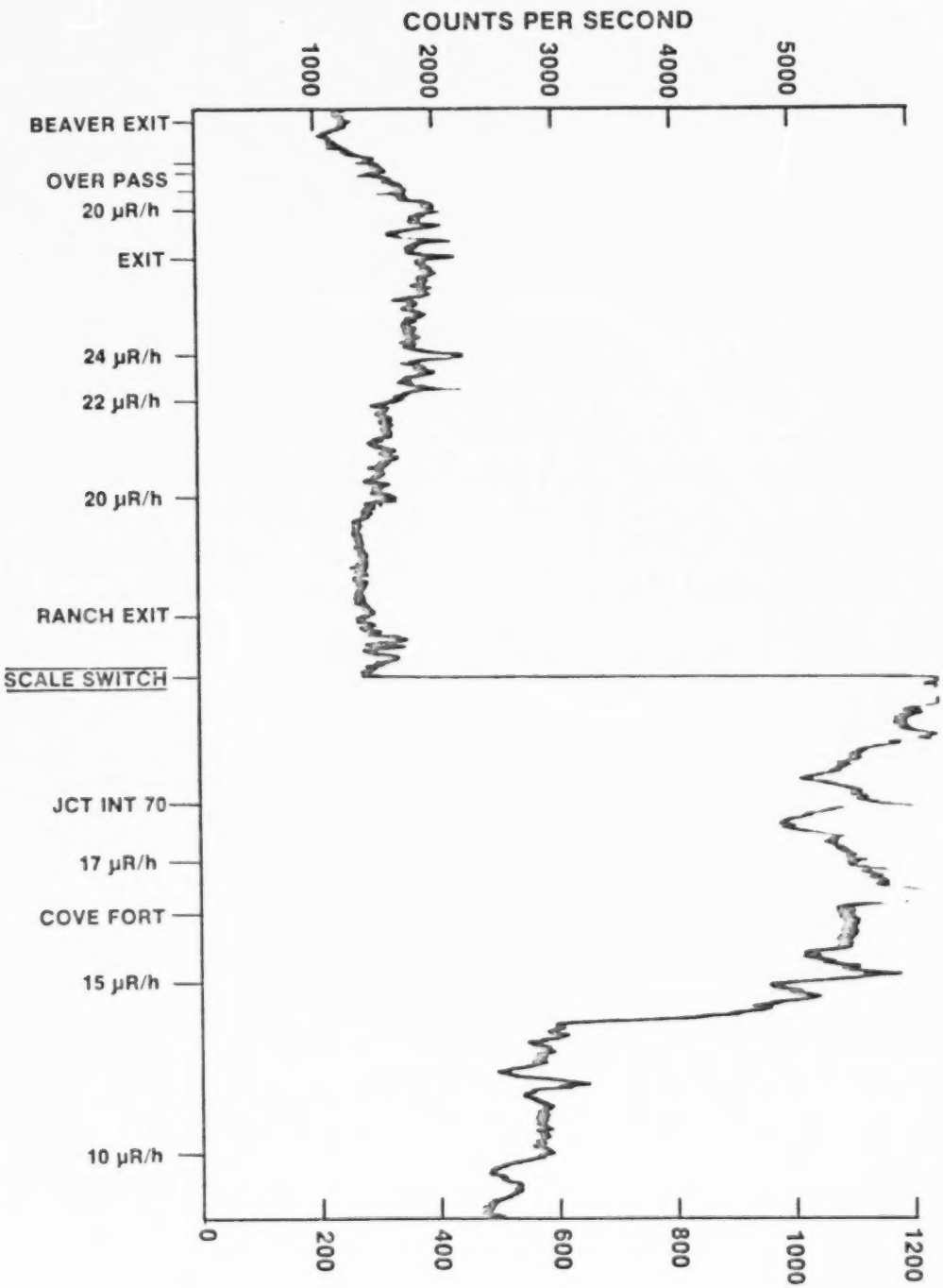

Figure 19. Gamma ray log on Interstate 15.

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APPENDIX A

ESTIMATION OF GAMMA EXPOSURE RATES AT CURBSIDE FROM STRUCTURES CONTAINING URANIUM MILL TAILINGS OR PHOSPHATE SLAG

1. Gamma exposure rate estimate at curbside from uranium mill tailings used for bedding material under a typical residential building slab

Assumptions used to estimate exposure rates:

Building area - 107 m^2

Slab - Square - 10.6 meter side

Slab to curbside distance - 7.6 meters

Tailings depth under slab - 15 cm

Radium-226 concentration of tailings - 500 pCi/g

Exposure rate calculations are based on a 30-cm x 15-cm tailings line source behind a 20-cm stem wall and no self-absorption. The energy flux along a perpendicular bisector of a line source is estimated by the following equation (Fitzgerald et al., 1967).

$$I_o = (2.96 \times 10^9)\, C_L\, E\, n\, 2L/h^2 [1 - 1/3\,(L/h)^2 + 1/5\,(L/h)^4 - 1/7\,(L/h)^6 .....]$$

Where: I_o = Unattenuated energy flux at curbside from the assumed line source (Mev/cm^2-sec)

C_L = Radium-226 concentration per unit length of line source (Ci/cm)

L = Length of line source (cm)

E = Energy of gamma radiation (Mev)

h = Perpendicular distance from line source to point of measurement (cm)

n = Gamma ray photon abundance

$$(2.96 \times 10^9) = \frac{3.7 \times 10^{10}\ \text{d/sec-Ci}}{4\pi}$$

Assumed active volume of tailings behind footing stem wall

$V = 1060\ cm \times 15\ cm \times 30\ cm = 4.8 \times 10^5\ cm^3$

Total activity of radium-226 in active tailings volume $= 500\ pCi/g \times 1.6\ g/cm^3 \times 4.8 \times 10^5\ cm^3 = 3.8 \times 10^8\ pCi$

$$C_L = 3.8 \times 10^8\ pCi \times 1/1060\ cm = 3.6 \times 10^5\ pCi/cm$$

$$I_o = 2.96 \times 10^9 \left(\frac{3.7 \times 10^5\ pCi/cm}{1.0 \times 10^{12}\ pCi/Ci}\right)(0.8\ MeV/dis)(2.18)(2)\frac{(1.06 \times 10^3\ cm)}{(762\ cm)^2}[1-0.225+0.09]$$

$$I_o = 7.0\ MeV/cm^2\text{-sec}$$

Unattenuated exposure rate at curbside $= \frac{I_o}{5.2 \times 10^5\ MeV/cm^2\text{-sec-R/h}} = 7/5.2 \times 10^5 = 13 \times 10^{-6}\ R/h = 13\ \mu R/h$

Correcting for attenuation by the 20-cm concrete stem wall, the transmission factor is 0.2 (U.S. DHEW, 1960).

Estimated exposure rate $= 13\ \mu R/h \times 0.2 = 2.6\ \mu R/h$

2. Gamma exposure rate at curbside from phosphate slag used as aggregate in concrete

   Assumptions used to estimate exposure rates

   Building area - 107 m^2

   Exposed wall - 91 cm high

   Wall to curbside distance - 7.6 m

   Wall length - 10.6 m

   Radium-226 concentration - 15 pCi/g in wall

Wall volume $= 1.96 \times 10^6\ cm^3$

Total radium-226 in stem wall $= 1.96 \times 10^6\ cm^3 \times 15\ pCi/g \times 2.35\ g/cm^3 = 6.91 \times 10^7\ pCi$

Radium-226 concentration per unit length of stem wall $= \frac{6.91 \times 10^7\ pCi}{1.06 \times 10^3\ cm} = 6.58 \times 10^4\ pCi/cm$